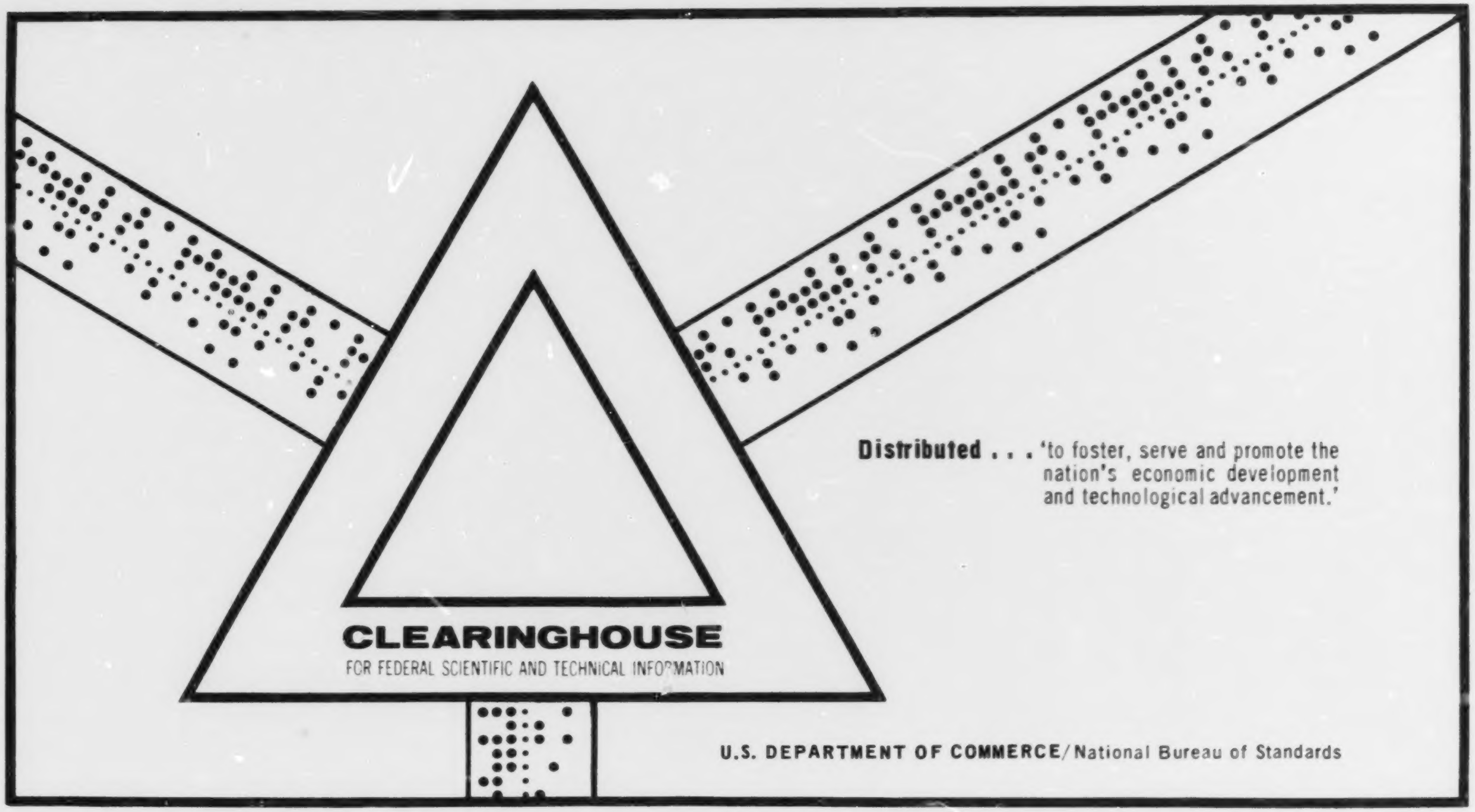
PB 188 089

# AIR POLLUTION ASPECTS OF ODOROUS COMPOUNDS

Ralph J. Sullivan

Litton Systems, Incorporated
Bethesda, Maryland

September 1969



**CLEARINGHOUSE**
FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION

**Distributed . . .** 'to foster, serve and promote the nation's economic development and technological advancement.'

**U.S. DEPARTMENT OF COMMERCE**/National Bureau of Standards

**This document has been approved for public release and sale.**

PB188089

[redacted]

# TECHNICAL REPORT

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

ENVIRONMENTAL SYSTEMS A Division of Litton Industries, Inc. 7300 PEARL STREET, BETHESDA, MARYLAND 20014

# AIR POLLUTION ASPECTS
# OF
# ODOROUS COMPOUNDS

Prepared for the
National Air Pollution Control Administration
Consumer Protection & Environmental Health Service
Department of Health, Education, and Welfare
(Contract No. PH-22-68-25)

Compiled by Ralph J. Sullivan

Litton Systems, Inc.
Environmental Systems Division
7300 Pearl Street
Bethesda, Maryland 20014

September 1969

## FOREWORD

As the concern for air quality grows, so does the concern over the less ubiquitous but potentially harmful contaminants that are in our atmosphere. Thirty such pollutants have been identified, and available information has been summarized in a series of reports describing their sources, distribution, effects, and control technology for their abatement.

A total of 27 reports have been prepared covering the 30 pollutants. These reports were developed under contract for the National Air Pollution Control Administration (NAPCA) by Litton Systems, Inc. The complete listing is as follows:

Aeroallergens (pollens)
Aldehydes (includes acrolein and formaldehyde)
Ammonia
Arsenic and Its Compounds
Asbestos
Barium and Its Compounds
Beryllium and Its Compounds
Biological Aerosols (microorganisms)
Boron and Its Compounds
Cadmium and Its Compounds
Chlorine Gas
Chromium and Its Compounds (includes chromic acid)
Ethylene
Hydrochloric Acid
Hydrogen Sulfide
Iron and Its Compounds
Manganese and Its Compounds
Mercury and Its Compounds
Nickel and Its Compounds
Odorous Compounds
Organic Carcinogens
Pesticides
Phosphorus and Its Compounds
Radioactive Substances
Selenium and Its Compounds
Vanadium and Its Compounds
Zinc and Its Compounds

These reports represent current state-of-the-art literature reviews supplemented by discussions with selected knowledgeable individuals both within and outside the Federal Government. They do not however presume to be a synthesis of available information but rather a summary without an attempt to interpret or reconcile conflicting data. The reports are necessarily limited in their discussion of health effects for some pollutants to descriptions of occupational health exposures and animal laboratory studies since only a few epidemiologic studies were available.

Initially these reports were generally intended as internal documents within NAPCA to provide a basis for sound decision-making on program guidance for future research activities and to allow ranking of future activities relating to the development of criteria and control technology documents. However, it is apparent that these reports may also be of significant value to many others in air pollution control, such as State or local air pollution control officials, as a library of information on which to base informed decisions on pollutants to be controlled in their geographic areas. Additionally, these reports may stimulate scientific investigators to pursue research in needed areas. They also provide for the interested citizen readily available information about a given pollutant. Therefore, they are being given wide distribution with the assumption that they will be used with full knowledge of their value and limitations.

This series of reports was compiled and prepared by the Litton personnel listed below:

Ralph J. Sullivan
Quade R. Stahl, Ph.D.
Norman L. Durocher
Yanis C. Athanassiadis
Sydney Miner
Harold Finkelstein, Ph.D.
Douglas A. Olsen, Ph.D.
James L. Haynes

The NAPCA project officer for the contract was Ronald C. Campbell, assisted by Dr. Emanuel Landau and Gerald Chapman.

Appreciation is expressed to the many individuals both outside and within NAPCA who provided information and reviewed draft copies of these reports. Appreciation is also expressed to the NAPCA Office of Technical Information and Publications for their support in providing a significant portion of the technical literature.

# ABSTRACT

Offensive odors provoke people into complaining about air pollution. They may cause both mental and physiological effects such as nausea, headache, loss of sleep, loss of appetite, impaired breathing, and in some cases allergic reactions. Community and personal pride and status may be adversely affected by obnoxious odors in the vicinity. Although some governmental agencies have enacted laws prohibiting air pollution that interferes with the reasonable enjoyment of life and property, no odor pollution standards have been established.

The most offensive odors come from kraft paper mills, animal rendering plants, chemical plants, petroleum refineries, diesel engines, sewers and sewage treatment plants, and metallurgical plants. Other sources include industrial, domestic, and natural odors. These smells often pollute an area 10 to 20 miles from the source.

Several methods have been developed for abating most odor pollution problems. The most generally accepted method is incineration at the source. However, this may be supplemented or replaced with any of several other methods such as adsorption, chemical scrubbing, containment, process changes, and masking or counteracting the odors.

Economically, odor pollution depresses property values. The cost of abatement depends on the odor pollution problem and the source.

The human nose is the only reliable detector, and several laboratory and field methods have been developed to quantify human observations.

## CONTENTS

FOREWORD

ABSTRACT

1. INTRODUCTION . . . . . . . . . . . . . . . . . . . . . 1

2. EFFECTS . . . . . . . . . . . . . . . . . . . . . . . 4

- 2.1 Effects on Humans . . . . . . . . . . . . . . 4
  - 2.1.1 Characteristics of Odors . . . . . . 4
    - 2.1.1.1 Odor Intensity . . . . . . 4
    - 2.1.1.2 Odor Quality . . . . . . . 9
    - 2.1.1.3 Odor Acceptability . . . . 14
    - 2.1.1.4 Odor Pervasiveness . . . . 15
  - 2.1.2 Physiological and Psychological Aspects of Odors . . . . . . . . . . . 16
    - 2.1.2.1 Public Opinion . . . . . . 19
    - 2.1.2.2 Allergies and Odors . . . . 24
  - 2.1.3 Theories of Olfaction . . . . . . . . 30
- 2.2 Effects on Animals . . . . . . . . . . . . . 33
  - 2.2.1 Commercial and Domestic Animals . . 33
  - 2.2.2 Experimental Animals . . . . . . . . 33
- 2.3 Effects on Plants . . . . . . . . . . . . . . 33
- 2.4 Effects on Materials . . . . . . . . . . . . 34
- 2.5 Environmental Air Standards . . . . . . . . 34

3. SOURCES . . . . . . . . . . . . . . . . . . . . . . . 37

- 3.1 Natural Occurrence . . . . . . . . . . . . . 39
- 3.2 Production Sources . . . . . . . . . . . . . 41
  - 3.2.1 Petroleum Industry . . . . . . . . . . 41
  - 3.2.2 Petrochemical Plant Complexes . . . 45
  - 3.2.3 Chemical Industry . . . . . . . . . . 45
  - 3.2.4 Pulp and Paper Mills . . . . . . . . 47
  - 3.2.5 Coke Ovens and Coal . . . . . . . . . 51
  - 3.2.6 Iron-Steel Industry and Foundries . 52
  - 3.2.7 Food Processing . . . . . . . . . . . 53
  - 3.2.8 Meat Industry . . . . . . . . . . . . 54
    - 3.2.8.1 Feedlots . . . . . . . . . . 54
    - 3.2.8.2 Livestock Slaughtering . . 56
    - 3.2.8.3 Inedible Rendering of Animal Matter . . . . . . . 57
    - 3.2.8.4 Fish Processing . . . . . . 61
    - 3.2.8.5 Edible Meats . . . . . . . . 62
    - 3.2.8.6 Tanneries . . . . . . . . . 62
  - 3.2.9 Miscellaneous Production Sources . . 63

CONTENTS (Continued)

3.3 Product Sources . . . . . . . . . . . . . . . . 63
3.4 Other Sources . . . . . . . . . . . . . . . . . 63
    3.4.1 Combustion Processes . . . . . . . . . 63
        3.4.1.1 Diesel Engine Odors . . . . 65
        3.4.1.2 Aircraft Odors . . . . . . . 73
    3.4.2 Sewage . . . . . . . . . . . . . . . . 75
    3.4.3 Miscellaneous Other Sources . . . . 77
3.5 Environmental Air Concentrations . . . . . 78

4. ABATEMENT . . . . . . . . . . . . . . . . . . . . 79

4.1 Petroleum Industry . . . . . . . . . . . . . 85
4.2 Chemical Industry . . . . . . . . . . . . . . 85
4.3 Pulp and Paper Mills . . . . . . . . . . . . 86
4.4 Coke Ovens and Coal . . . . . . . . . . . . . 91
4.5 Diesel Engine Odors . . . . . . . . . . . . . 92
4.6 Meat Industry . . . . . . . . . . . . . . . . 93
    4.6.1 Feedlots . . . . . . . . . . . . . . . 93
    4.6.2 Livestock Slaughtering . . . . . . . . 95
    4.6.3 Inedible Rendering of Animal Matter 96
4.7 Sewage . . . . . . . . . . . . . . . . . . . . 98

5. ECONOMICS . . . . . . . . . . . . . . . . . . . . 100

6. METHODS OF ANALYSIS . . . . . . . . . . . . . . 105

6.1 Sampling Methods . . . . . . . . . . . . . . 105
6.2 Qualitative Methods . . . . . . . . . . . . . 105
6.3 Quantitative Methods . . . . . . . . . . . . 106
    6.3.1 Organoleptic Methods . . . . . . . . . 106
    6.3.2 Instrumental Methods . . . . . . . . . 110

7. SUMMARY AND CONCLUSIONS . . . . . . . . . . . . 111

REFERENCES . . . . . . . . . . . . . . . . . . . . . 115

APPENDIX A . . . . . . . . . . . . . . . . . . . . . 153

APPENDIX B . . . . . . . . . . . . . . . . . . . . . 156

APPENDIX C . . . . . . . . . . . . . . . . . . . . . 241

# LIST OF FIGURES

1. Odor Quality Chart . . . . . . . . . . . . . . . . . . 153

2. Location of Kraft Mills in the United States . . . . 154

3. Typical Rates of Odor Emissions and of Vapor Emissions from a Batch-Type Rendering Cooker Reducing Inedible Animal Matter . . . . . . . . . . . 155

## LIST OF TABLES

1. Reported Odor Threshold Concentrations of Hydrogen Sulfide . . . . . . . . . . . . . . . . . . . . . . 156

2. Recognition Odor Threshold of Odorants . . . . . . . 157

3. Odor Addition or Synergism in Mixtures . . . . . . . 170

4. Crocker-Henderson Odor Classification Standards . . . 171

5. Amoore Classification of Odor Quality . . . . . . . . 172

6. Odor Qualities of Selected Odorants . . . . . . . . . 173

7. Public Opinion Surveys Relating Odors to Air Pollution . . . . . . . . . . . . . . . . . . . . . 194

8. Complaints Relating Odors to Property Damage and Health in Terre Haute, Ind. . . . . . . . . . . . . 194

9. Odors by Time of Day in the St. Louis Metropolitan Area . . . . . . . . . . . . . . . . . . . . . . . 195

10. Effect of the Day of the Week on Odor Nuisance Occurrences . . . . . . . . . . . . . . . . . . . . 196

11. Effect of the Time of Day on Odor Nuisance Occurrences . . . . . . . . . . . . . . . . . . . . 196

12. Effect of Temperature on Odor Nuisance Occurrences . 197

13. Effect of Atmospheric Pressure on Odor Nuisance Occurrences . . . . . . . . . . . . . . . . . . . . 197

14. Effect of Relative Humidity on Odor Nuisance Occurrences . . . . . . . . . . . . . . . . . . . . 198

15. Effect of Wind Velocity on Odor Nuisance Occurrences . . . . . . . . . . . . . . . . . . . . 198

16. Effect of Changing Temperature, Pressure, and Relative Humidity on Odor Nuisance Occurrences . . . 199

17. Effect of Time of Year on Odor Nuisance Occurrences . 199

18. Theories of Olfaction . . . . . . . . . . . . . . . 200

19. Most Frequently Reported Odor Sources . . . . . . . . 203

20. Nature of Air Contaminants Emanating from Various Types of Sources . . . . . . . . . . . . . . . . . . 205

21. Odor Concentration Measured in Various Plants . . . . 206

22. Atmospheric Contaminants Recovered from Charcoal after 30-Day Manned Experiment . . . . . . . . . . . 207

23. Potential Sources of Odorous Emissions from Oil Refineries . . . . . . . . . . . . . . . . . . . . . . 208

24. Crude Oil Capacity in the United States as of January 1969 . . . . . . . . . . . . . . . . . . . 209

25. Sulfur Production from Hydrogen Sulfide in the United States . . . . . . . . . . . . . . . . . . . . . 210

26. Range of Sulfur Gas Concentrations Encountered in Kraft Mill Sampling . . . . . . . . . . . . . . . . . 211

27. Estimated Emissions from Kraft Pulp Mill in Lewiston, Idaho . . . . . . . . . . . . . . . . . . . 212

28. November Odor Survey in Lewiston-Clarkston Area . . . 213

29. April Odor Survey in Lewiston-Clarkston Area . . . . 214

30. Kraft Pulp Production in the United States . . . . . 215

31. Sources of Odorous Emissions in Coke Plants . . . . . 216

32. Odor Concentrations and Emission Rates from Inedible Reduction Processes . . . . . . . . . . . . 217

33. Typical Odor Emissions From Rotary Fish Meal Driers Without Odor Control . . . . . . . . . . . . . . . . . 218

34. Odor Emissions from Apartment House Incinerators . . 219

35. Odor Intensity of Diesel Exhaust and Concentration of Aldehydes (as Formaldehyde) . . . . . . . . . . . 220

36. Computed Concentrations at Odor Thresholds of Diluted Diesel Exhaust . . . . . . . . . . . . . . . . . . . 221

37. Analysis of Diesel Engine Exhaust . . . . . . . . . . 222

38. Diesel Exhaust Emissions and Percent of Time at Each Power Setting for Two-Cycle Diesel Bus Operating in Detroit . . . . . . . . . . . . . . . . . . . . . . . 223

39. Odor Emissions from Jet Aircraft Exhaust . . . . . . 224

40. Number, Type, and Location of Odor Observations Near John F. Kennedy Airport . . . . . . . . . . . . . . . . 225

41. Control of Odors by Incineration . . . . . . . . . . . 227

42. Odor Emissions from Typical Industrial Equipment and Odor Control Devices . . . . . . . . . . . . . . . . 228

43. Odor Removal Efficiencies of Condensers or Afterburners, or Both, Venting a Typical Dry Rendering Cooker . . . . . . . . . . . . . . . . . . . 232

44. Odor Reduction in Polluted Air by Potassium Permanganate . . . . . . . . . . . . . . . . . . . . . 233

45. Typical Costs of Basic and Control Equipment Installed in Los Angeles County . . . . . . . . . . . 234

46. Control Expenditures by Types of Emissions in the Petroleum Industry . . . . . . . . . . . . . . . . . . 239

47. Economic Analysis of Three Types of Condensers for Rendering Plants . . . . . . . . . . . . . . . . . . . 240

## 1. INTRODUCTION

Odorous compounds may have pleasant or unpleasant odors: an odor which is quite acceptable to one person may be unacceptable to another person. Although the quality of an odor is highly subjective, all healthy people are usually aware of odors and generally agree that some odorous compounds are obnoxious. Some of these offensive odors can be detected when the odorant is present in very low concentrations. For these reasons, malodors are one of the first manifestations of air pollution, and they frequently arouse extreme emotional reactions in people. Offensive odors are capable of producing nausea, vomiting, and headache; curbing the appetite, impairing nutrition, and curtailing water intake; disturbing sleep; upsetting the stomach; hampering proper breathing; offending the senses; and interfering with enjoyment of property. Most of all, bad odors can mar good dispositions and provoke emotional disturbances, mental depression, and irritability.[126]

Sociologically, such noxious odors can ruin personal and community pride, interfere with human relations in various ways, discourage capital improvements, lower socioeconomic status, and damage a community's reputation. Economically, they can stifle growth and development of a community. Both industry and labor prefer to locate in a desirable area in which to live, work, and play; and the natural tendency is to avoid communities with obvious odor problems. Tourists also shun such areas. The resulting decline in property values, tax revenues, payrolls, and sales can be disastrous to a community.[126]

No instrument has been developed with the sensitivity and versatility of the human nose for odor detection. Therefore, the methods currently used for odor measurement involve personal judgments by one or more people; results obtained are expensive and lack the desired precision.

The mode of expressing observation results is strictly of a qualitative nature. It is based largely upon the olfactory sense without any guide beyond human ability to associate and describe personal reaction. As a result, odors are often given such descriptive terms as dead-cat, wet-dog, manurial, rotten-egg, spoiled-fish, and others. In addition, the intensity of the odor is often rated on an arbitrary scale of 1 to 5. Such a system, of course, depends to a great degree upon the acuity of the observer's nose, his past experiences, and his ability to describe his reaction accurately. The most useful observation from an engineering point of view is to measure the number of dilutions which are necessary to reduce the odorant to the odor threshold concentration.

Odor may be defined as the sensation of smell perceived as a result of olfactory stimulus.[65] An odorant is a substance or mixture of substances that produces the sensation of smell.[65]

The scope of this report is limited to the odor _per se_, not the toxic or chemical aspects of odorants. The reader is referred to the companion reports of this series for the toxic and chemical aspects of some odorous substances, such as hydrogen sulfide, aldehydes, chlorine, hydrochloric acid, ammonia, and ethylene.

# 2. EFFECTS

## 2.1 Effects on Humans

To keep alive man must breathe. A single sniff of air may delight him with the perfume of vanillin, may nauseate him with a fecal odor, may warn him of the presence of toxic quantities of hydrogen sulfide, or may start his digestive juices flowing with the aroma of a broiling steak. Thus, odors may affect man in various ways, depending not only on the characteristics of the odor, but also on the particular man and his environment.

### 2.1.1 Characteristics of Odors

#### 2.1.1.1 Odor Intensity

The human nose is an extremely sensitive gaseous detector. It can respond to thousands of different odor stimuli and detect both low and high concentrations of gaseous materials simultaneously. Moreover, the odorants may originate from sources at relatively great distances away. The intensity of the odor is defined as the numerical or verbal indication of the strength of an odor.[294]

Experimental findings on discerning odor intensity show that an average observer can distinguish between three intensities--weak, medium, and strong--whereas a trained observer may distinguish between five degrees of intensity,[294] and an expert can distinguish six.[190] Since 1920, experts have been rating the intensity of various odors by using the following scale:

| Odor Intensity | Expert Description[140] |
|---|---|
| 0 | No odor |
| 1 | Very faint |
| 2 | Faint |
| 3 | Easily noticeable |
| 4 | Strong |
| 5 | Very strong |

Trained observers have used[290,294] the following scale to determine the odor intensity of tobacco smoke, as well as of domestic and industrial odors:

| Odor Intensity | Odor Description[22] |
|---|---|
| 0 | A concentration of an odorant which produces no sensation. |
| 1 | Concentration which is just detectable (the threshold dilution). |
| 2 | A distinct and definite odor whose unpleasant characteristics are revealed or foreshadowed (the recognition threshold). |
| 3 | An odor strong enough to cause a person to attempt to avoid it completely. |

4 An odor so strong as to be overpowering and intolerable for any length of time.

The sensation of intensity of an odor varies exponentially with the concentration of the odorant. This phenomenon is described by the well-known Weber-Fechner Psychophysical Law, which states that the intensity of the sensation is proportional to the logarithm of the strength of the stimulus. For the sensation of odor this may be expressed as

$$I = k \ln C$$

where I is the intensity of the odor sensation
k is a constant
and C is the concentration of odorant.

The data for three odorants, ethyl mercaptan, butyl thioether, and crotonaldehyde, follow this law over extremely large changes in concentrations. The range of intensity from 0 to 5 covers eight log cycles for ethyl mercaptan, six for butyl thioether, and four for crotonaldehyde.[36]

The concentration of odorant that just gives an intensity of zero may be defined as the detection threshold concentration.[127,217] However, this odor threshold concentration is more commonly defined as the minimum concentration which will result in the stimulation of the olfactory nerves. All people do not have the same sensitivity for detection of odors.[190] Therefore, an odor panel may be used to determine the odor threshold concentration.[26] As a result, the odor threshold may be reported as the "effective dosage" where 100 percent ($ED_{100}$), 50 percent ($ED_{50}$), or 0 percent ($ED_0$) of panelists perceive the odor. $ED_{50}$ is the most commonly used. Tests are usually conducted to eliminate persons either highly sensitive or insensitive to odors from odor panels. (These tests are described in Section 6 .)

Two other bases of determining odor concentrations have been used: a recognition threshold concentration--the concentration at which the odor quality can be recognized; and the objectionability concentration--the concentration where the odor becomes objectionable. Leonardos et al.[154] have argued that the recognition sensation is more reproducible than the detection sensation.

Unfortunately, odor threshold measurements depend largely on the purity of the odorant. Therefore, odor threshold concentrations of "pure" odorants vary widely, often overlapping both detection and recognition threshold concentrations. For example, the reported odor threshold concentrations of hydrogen sulfide as shown in Table 1, Appendix B, vary from 0.65 to 1,400 μg/m³. Odor recognition threshold concentrations of odorants are listed in Table 2, Appendix B.

The intensities of a mixture of odorants may be independent, counteractive, additive, or synergistic.[236] For example, if odorants A and B are mixed, the odor intensity (I) may be

Independence

$$I_{AB} = k \ln (C_A \text{ or } C_B)$$

Counteraction

$$I_{AB} < k \ln (C_A \text{ or } C_B)$$

Addition

$$I_{AB} = k \ln (C_A + C_B)$$

Synergism

$$I_{AB} > k \ln (C_A + C_B)$$

Mixtures of butanol and pyridine showed an additive effect on the odor intensity at the odor threshold, whereas the addition of p-cresol to the mixture showed a synergistic effect, as shown in Table 3, Appendix B.

Tkach[281] reported that the odors of acetone and acetophenone are additive, and Stayzhkin[257] reported that the odors of hydrochloric acid and chlorine are additive.

Horstman et al.[116] have listed some of the factors which reportedly influence the olfactory sensitivity:

(1) The odor sensitivity of the individual observer varies from day to day, but the overall sensitivity of a group of observers is reasonably constant.

(2) The sense of smell becomes rapidly fatigued, though fatigue for one odor does not necessarily affect the perception of dissimilar odors.

(3) Responses to odors are not completely objective since psychological responses vary in different observers. What is unpleasant to one observer may be quite acceptable to another, and so may not be noted.

(4) The sensitivity of observers varies widely; some have extreme sensitivity while others are incapable of smelling an odor. The age of the observer seems to have an effect on sensitivity: sensitivity reaches a maximum at puberty and decreases with age.

(5) Meteorological factors influence reported odor levels; wind speed and vertical temperature gradient influence the dilution of odors. Temperature and humidity affect odor perception, but there is considerable disagreement about their precise influence.

#### 2.1.1.2 Odor Quality

Odor quality is a verbal description of the odor. The quality may be described in terms of such familiar odorants as coffee, onions, lemons (characteristic odors), or by associating an unfamiliar odor with a familiar odor. The observer often does not possess the vocabulary to describe the odor he smells. Sumner[272] suggests that there may be 2,500 olfactory receptors, each capable of detecting a different quality of odor, and the combination of these odors may produce hundreds of thousands of odor qualities. As a result of the complexity of describing odors, various systems have been devised to classify the odor quality, thus providing an observer with a vocabulary for odor description. Gruber[96] reported a "clock" chart attributed to Dean Foster.* This chart is presented in Figure 1, Appendix A.

McCord and Witheridge[170] have listed three different systems for classifying odor quality, as follows:

A. Zwaardemaker's classification has nine categories:

(1) Ethereal or fruity: characteristic in general of fruits and due in most cases to the presence of various esters; includes also beeswax and certain ethers, aldehydes, and ketones

(2) Aromatic

- a. Camphoraceous: borneol, camphor, eucalyptole
- b. Spicy: eugenol, ginger, pepper, cinnamon, cassia, mace

---

*Head of the Psychophysical Laboratory at the Joseph E. Seagram Co., Louisville, Ky.

c. Anise-lavender: anethole, lavender, menthol, thymol, safrole, peppermint

d. Lemon-rose: geraniol, citral, linalyl acetate, sandalwood

e. Amygdalin: benzaldehyde, oil of bitter almond, nitrobenzene, prussic acid, salicylaldehyde

(3) Fragrant or balsamic

a. Floral: jasmine, ilang-ilang, orange blossom, lilac, terpineol, lily of the valley

b. Lily: tuberose, narcissus, hyacinth, orris, violet, ionone, mignonette

c. Balsamic: vanillin, piperonal, coumarin, balsams of Peru and Tolu

(4) Ambrosial: musk and amber. Present in the flesh, blood, and excreta of certain animals

(5) Alliaceous or garlic: onion, garlic, and many compounds of sulfur, selenium, tellurium, and arsenic

a. Alliaceous: hydrides of sulfur, selenium, and tellurium, mercaptans, organic sulfides, thioacetone, asafetida

b. Cacodyl fish odors: hydrides of phosphorus and arsenic, cacodyl compounds, trimethylamine

c. Bromine odors: bromine, chlorine, quinone

(6) Empyreumatic or burnt: as in tar, baked bread, roasted coffee, tobacco, benzene, naphthalene, phenol, and products of the dry distillation of wood

(7) Hircine or goaty: due in the case of this animal to the caproic and caprylic esters contained in the sweat and typified also by perspiration and cheese

(8) Repulsive: such as given off by many of the narcotic plants and by acanthus

(9) Nauseating or fetid: such as given off by products of putrefaction (feces, etc.) and by certain plants

B. Henning's odor classification lists only six basic qualities:

(1) Spicy: conspicuous in cloves, cinnamon, nutmeg, etc.

(2) Flowery: conspicuous in heliotrope, jasmine, etc.

(3) Fruity: conspicuous in apple, orange oil, vinegar, etc.

(4) Resinous: conspicuous in coniferous oils and turpentine

(5) Foul: conspicuous in hydrogen sulfide and products of decay

(6) Burnt: conspicuous in tarry and scorched substances

C. The Crocker-Henderson classification is represented by four fundamental odor sensations:

(1) Fragrant or sweet

(2) Acid or sour

(3) Burnt or empyreumatic

(4) Caprylic, goaty, or oenanthic

These four fundamental odor sensations were ranked in intensity from 0 to 8 and expressed as four-digit numbers for each odorant. On this basis a substance without odor would appear as 0000. Ethanol appears as 5414. The first digit represents the fragrant character; the second digit, acid; the third, burnt; and the fourth, caprylic. The odor standards listed in Table 4, Appendix B, serve to illustrate the numerical method of coding the odor quality.

Amoore[12] has determined the number of fundamental odors by arranging some 600 compounds into groups with similar odors. The odors that occurred most frequently were assumed to be the primary odors--the first seven odors listed in Table 5, Appendix B.

Moncrieff[190] has listed the odor quality of a large number of odorants. A representative number of these have been listed in Table 6, Appendix B.

The untrained observer has difficulty using any of the above systems for odor description and must resort to using common terms to describe the odor. Horstman et al.[116] allowed student observers to describe the odor quality in their own words and then reduced the odor qualities to the following:

| Code | Odor Description |
|---|---|
| 0 | flowers |
| 1 | pulp mill |
| 2 | smoke, woodsmoke |

| | |
|---|---|
| 3 | burning leaves |
| 4 | mustiness |
| 5 | gasoline |
| 6 | rendering plant |
| 7 | rubbish burning |
| 8 | animal odors |
| 9 | miscellaneous odors |
| none | no odor |

The odor quality may change with dilution. In mixtures of odorants this may be because one odorant is more pervasive than the other odorant. Single component systems may also exhibit quality changes on dilution. The reason for this is not fully understood.[272]

### 2.1.1.3 Odor Acceptability

An odor may be either acceptable or unacceptable depending on its intensity and quality. The odors of new-mown hay or honeysuckle and roses are indicative of acceptable odors at normal concentrations. However, obnoxious odors may be unacceptable at much lower concentrations and become acceptable only at very low intensities. At high intensities the normally acceptable perfumes can be unacceptable.[272]

Moncrieff[191] studied the acceptability of 132 odors and ranked them according to their acceptability. Those compounds found least acceptable were mercaptans, sulfides, disulfides, amines, and aldehydes. He also observed that various people have odor preferences depending on age, sex, vocation, and environment. From these observations he wrote 124 rules of odor preference.

### 2.1.1.4 Odor Pervasiveness

Odor pervasiveness is the ability of an odor to pervade a large volume of air and still continue to possess a detectable intensity. Nadar[195] referred to it as odor potential or threshold dilution ratios. An odor unit* has been defined to describe the number of dilutions necessary to reduce the odor to the threshold concentration. A pervasive odor is one whose odor intensity changes very little on dilution. Mathematically, the pervasiveness is indicated by the slope (value of k) in the Weber-Fechner equation (Section 2.1.1.1). The pervasiveness increases as the value of k decreases. Of the three odorants mentioned in Section 2.1.1.1, ethyl mercaptan is more pervasive than butyl thioether, which in turn is more pervasive than crotonaldehyde.

---

*The number of odor units is equal to the volumes (standard cubic feet) of air necessary to dilute the concentration of odorant in one volume (standard cubic foot) of air to the threshold concentration. For example, 100 odor units/scf require 99 cubic feet of dilution air to reduce the odorant in one cubic foot of air to the threshold concentration.

### 2.1.2 Physiological and Psychological Aspects of Odors

The influence of odors on the health and comfort of man is difficult to prove. Odors in themselves are usually not the cause of organic disease. However, the odorant may incite an allergic response. It is obvious that some highly toxic substances, such as hydrogen sulfide, are associated with offensive odors; but the dangerous properties of these types of substances do not derive from the odor itself. In fact, odor is valuable in serving as a warning of the presence of an injurious gas. Odor bears no relationship to toxicity, and some poisonous gases are odorless or have a rather pleasant odor. McCord and Witheridge[170] have indicated that foul odors may cause poor appetite for food, lowered water consumption, impaired respiration, nausea and vomiting, insomnia, and "mental perturbation."

Winslow and Palmer[301] exposed human subjects* to the ordinary air of an unventilated room containing whatever polluting substances were given off by their bodies and garments. These persons were exposed 4 to 7 hours daily. The chief findings were that there were differences in food consumption on test days and control days. About 5 percent more food was consumed when the supply of air was fresh. The authors concluded that breathing the stale air diminished food intake.

---

*Number of persons exposed was not reported.

In another study, Winslow and Herrington[300] exposed eight young men four or five mornings each week for several winter months to an odor recognized as heated house dust. The test odor was emitted into the room slowly so that subjects were unaware of which days were test days. Olfactory fatigue prevented them from perceiving the odor, while an observer entering the test room would immediately recognize the odor. The consumption of the noon meal was evaluated as part of the test. There was no difference in the consumption of potato salad on test and control days, but macaroni and cheese showed a 13 percent rejection on odor test days. As the test progressed, this rejection decreased to 6 percent.

McCord and Witheridge[170] report that odors appearing in drinking water immediately cause a community to resort to bottled drinks. However, at sulfur spring spas, people will joyously drink the odoriferous liquid, at times relying on the odors themselves to restore health.

McCord and Witheridge[170] also point out that respiration may be impaired. When an unwanted odor is in the air, the tendency is to engage in two or three deep appraising sniffs. If the odor is deemed offensive, the person will resort to shallow, slow breaths or mouth breathing to avoid the odor. Where the odor is widespread in a community, windows and doors may be sealed in an attempt to keep out the odor. The investigators state that in some cases odors may produce nausea and vomiting. Occasionally, the presence of continuous odors may induce persistent vomiting.

The most frequent effects of odors on human health, according to McCord and Witheridge,[170] are insomnia and mental perturbation. They point out that many people regularly have difficulty sleeping and that any disturbance may prevent sleep, often after the person has been aroused from a deep sleep by an offensive odor. They admit that the extent to which odors contribute to loss of sleep cannot be proved; but they assert that odors do cause loss of sleep and, therefore, affect the health of a community. Long continuous exposure to offensive odors arouses a person to anger. Otherwise calm persons may become mildly maniacal, hysterical, and capable of carrying out acts entirely foreign to their usual natures. Thus odors may affect the mental health of a person.

Petri[213] states that malodorous substances may cause headaches, nausea, and similar phenomena. Even inherently fragrant substances, such as flavorings and chocolates, can cause considerable discomfort with protracted exposure, or at high concentrations. According to Petri, the psychological effects of an odor are highly subjective. Thus, the nuisance value of an odor depends on the attitude of the person, his disposition, and the time of day.

Air pollution in the form of malodors has been cited as the reason for certain lawsuits, picketing, rioting, and even forceful closure of plants.[124]

### 2.1.2.1 Public Opinion

Opinion surveys often place offensive odors at the top of the list of air pollutants. However, this is not always the case but depends largely on the type of pollution within the city. Table 7, Appendix B, shows the results of some surveys which have been made. The data presented in Table 7 were taken from opinion surveys in which questions were asked such as "What do you think the words 'Air Pollution' mean to most people in this area?" Possible multiple choice answers were listed as "frequent bad smells," "too much dust," "frequent haze," etc. Jonsson[136] points out that the results of any opinion survey depend on how the question is worded and the groups surveyed--their socio-economic status, education, age, and sex. Therefore, it is difficult if not impossible to compare results of surveys taken in different areas using different questionnaires. Moreover, the problems of measuring reactions to odors have not been solved, nor have methods been developed for adequately measuring the odor exposure in an area. Some examples of reactions to odors and attempts to assess the odor pollution effect on the health and welfare of the population are presented below.

Where a large percentage of the people are affected, concern about odors is often high. The frequent bad smells emanating from a pulp mill in Lewiston, Idaho--about 4 miles upwind from Clarkston, Wash.--resulted in a petition signed by 495 of the 7,000 residents of Clarkston. It read, in part, "This contamination of our air and its odor affects us from headaches, watery eyes, runny noses, and breathing difficulties, to paint corrosion or other property damages. This area has put up with this problem for 17 years, which is long enough." One resident states, "I believe the horrible, rotten stench coming from the smokestacks of the Potlatch pulp mill here in Lewiston is killing me; I am afraid to remain here; I don't want my family or myself to die premature deaths."[6]

A cooperative study[172,268] of the air pollution problem in the Clarkston-Lewiston Valley revealed that malodorous gases, including hydrogen sulfide, organic mercaptans, and organic sulfides emitted from the kraft pulp mill, were the major air pollution problem. Studies showed that 12 times during the 5-year period 1957 to 1961 (or approximately twice each year) meteorological conditions existed which may have caused air pollution episodes lasting 48 hours or more.

Terre Haute, Ind., is another city where public opinion has run high against odor pollution. Complaints of odors causing health and property damage were received by the mayor, the police, the Board of Health, and U.S. Public Health Service representatives. The number of complaints received in a 2-week period are given in Table 8, Appendix B. These included claims of adverse effects on health (referring to nausea, vomiting, headaches, diarrhea, and throat irritation), with or without additional complaints referring to property damage (paint damage).[7]

A brief investigation[7] by a Public Health Service physician failed to show any increase in illnesses being treated by local physicians or admissions to the hospital. However, when the Public Health Service physician and an epidemiologist toured the affected areas, they themselves experienced nausea and throat irritation, accompanied by the obnoxious odors. Interviews with the complainants revealed that

(1) Two out of three who complained were women.

(2) Nineteen of twenty persons interviewed reported experiencing symptoms associated with odor air pollution.

Of a total of 65 individuals of all ages in the 20 households studied, 37 to 57 percent were reported to have symptoms.

(3) Affected individuals usually complained of more than one symptom: 13 complained of nausea, five complained of being awakened at night, five reported burning eyes, and four reported shortness of breath. Other symptoms reported were cough, headache, anorexia, acute asthma attack, nervousness, weight loss, diarrhea, fever, gagging, and heaviness in the chest.

(4) Eight of twenty did not list any gastrointestinal symptoms.

(5) The symptoms were usually short in duration and ceased when the odor became weaker or disappeared.

Ten local physicians who were consulted agreed that the city's malodorous air caused nausea, sleep disturbances, loss of appetite, and a distressing physical and emotional environment in which to live.[7]

Hydrogen sulfide concentration measurements showed good agreement between its concentration and the odor episodes. The most likely source was a 36-acre lagoon used for biodegradation of organic industrial wastes.[7]

Another odor episode occurred in St. Louis, Mo., on November 24, 1963, during an odor survey of the city. Over

100 complaints were registered with the St. Louis Police Department and Laclede Gas Company before 8:00 p.m. Although odor surveys were taken at 8:00, 10:00, and 12:00 p.m., the exact cause of the trouble was not pinpointed. However, it was postulated that an industrial breakdown or spill must have taken place on the Illinois side of the Mississippi River.[131] Firemen made the odor survey, and their reports of pleasant and unpleasant odors reflect public opinion to some degree. The results of their surveys are given in Table 9, Appendix B.

Huey *et al.*[118] have studied effects of the day of the week, time of day, temperature, atmospheric pressure, humidity, and wind velocity on the number of complaints received from residents near an animal rendering plant. The odors emitted from the plant were described as offensive, nauseating, repulsive, and repugnant. The data shown in Tables 10-17, Appendix B, indicate that the number of complaints (1) increases on weekends, (2) increases during the day, (3) increases with rising temperature, (4) is higher when atmospheric pressure is above 28.84 inches mercury, (5) increases with decreasing humidity, (6) does not change with wind velocity, and (7) is highest in the summer months.

In its 1960 report, "National Goals in Air Pollution Research," the Surgeon General's *ad hoc* task group on air pollution research goals states:[198] "The aspects of air pollution which are most apparent and of greatest personal concern to the individual are irritation to the eyes, nose, and throat; malodors; and reduction of visibility. The pollutants responsible for these effects are undesirable, whether or not they cause long-range health effects or economic losses, because they constitute an annoyance to people. The nuisance of these effects, together with those related to soiling, give rise to the greatest number of complaints received by air pollution control authorities. There is no doubt that a person's well-being is eventually affected by exposure to these sensory annoyances and that this may result in economic loss."

#### 2.1.2.2 Allergies and Odors

Odors may cause attacks of asthma or other allergic conditions. In 1882 Salter[246] described asthmatic attacks produced by effluvium from hay, smell of mustard, odors from skins of animals, smell of a lucifer match, odors from fermenting foods, odors from cheese, smell of violets, burning wood, smoky air, sulfur fumes, smell of paint, foul air in crowded rooms, gas escape, camphor, tobacco smoke, smell of linseed, smell of horses, cattle, dogs, and rabbits. In 1932 Feinberg and Aries[80] described asthma resulting from odors of cooking shrimp, beans, and lentils.

In many cases it is difficult to prove whether an allergic patient was affected by an odor or the odorant substance itself. Odorants from trees, shrubs, flowers, fabrics, animals, and household articles are ordinarily harmless to individuals not subject to allergies. However, these substances can, in small amounts under proper conditions, incite an allergic attack in sensitized individuals.[115]

Horesh[115] has reviewed the importance of nonspecific factors as provocateurs of allergic symptoms. He found odorous agents of etiological significance in asthma, allergic rhinitis, allergic croup and tracheitis, atopic dermatitis, urticaria, allergic headaches, and gastrointestinal allergy.

Odorous substances have been cited as causing allergic symptoms or illnesses by various authorities as follows:

| Odorous Substance | Reference |
|---|---|
| Cleaning fluid | 92 |
| Cooking odors | 92 |
| Feces | 130 |
| Fish | 60,64,79,288 |
| Food | 40,56,76,106,114,224, 226,240,262,271,275, 311 |
| Formaldehyde | 115,226 |
| Fresh paint | 59,60,92,279,288 |
| Furniture polish | 115 |

| | |
|---|---|
| Gasoline | 92 |
| Lighter fluid | 115 |
| Moth balls | 92 |
| Newspaper print | 84,115 |
| Oils | 33,262 |
| Perfume | 310 |
| Rubber | 115 |
| Spices | 115 |
| Tobacco smoke | 92,100,115,237,247,<br>276 |
| Turpentine | 288 |
| Wood smoke | 54,66,115,225 |

A questionnaire was devised by Brown and Colombo[34] to determine the number of their patients whose illnesses were significantly affected by odorants. A series of 200 patients in whom fumes, odors, and smells caused major symptoms was thus collected over a period of 10 years. Substances thought to be responsible were dimethyl sulfide, perfumes, cooking odors, gas, bleaching fluid, soap powders, deodorants, hair tonics, shaving lotions, fresh paint, kerosene, wood smoke, tobacco smoke, cleaning fluids, shoe polish, lighter fluid, spot removers, furniture polish, fluid insecticides, melting ironing wax, sweeping compounds and cedar dusts, freshly printed newspapers and typewriter ribbons, coal smoke from stoves or locomotives, pine wood, turpentine, moth balls, plastic furniture covers, floor wax, carbon paper, asphalt, chlordane, lindane, DDT, and weathered apples. A similar list of odors and fumes which cause directly or nonspecifically allergic reactions was compiled by Deamer.[54] Included were such items as gasoline odors, smoke from any source, gas, wood odors, paint odors, household odors such as ammonia and floor wax, cosmetics, and food odors.

Food odorants in low concentrations also commonly excite allergic symptoms. Horesh[112] reported on allergy to food odors and the role these odors play in the etiology of infantile atopic dermatitis. Foods most frequently incriminated were eggs and fish, although chicken, pork, bacon, and cabbage were also mentioned. Atopic dermatitis was reported in a series of nine cases--the majority infants, but some, older children. In these patients the allergic signs and symptoms were provoked or aggravated by the mere presence of the foods in the patient's environment.

Urbach[288] reviewed the effect of food odors on allergic symptoms up to 1941. He reported that allergic symptoms were elicited from the odors of the following foods: fish, milk, egg, asparagus, coffee, garlic, onion, sage, apple, and lemon.

That the odor rather than the pollen can be the cause of allergic symptoms has been reported by other investigators. Biederman[28] described effects from a number of flowers and presented experimental evidence to support his views that odor, not pollen, was the cause of the symptoms.

Urbach[288] accepted the possibility that pollens head the list of allergens responsible for most allergic rhinitis, but called attention to the frequently forgotten fact that plant odors can also be a cause. Urbach noted cases in which nasal symptoms or asthma were produced by the odors from roses, locust trees, linden trees, mock oranges, carnations, privet, lilies, common elders, lilacs, lilies of the valley, and violets. He also reported a patient who developed asthma from the odor of a pine forest, pine needle extract, and pine soap. Observations by Sticker,[262] Mackenzie,[160] and Goodale[94] showed that the fragrance of roses and certain other flowers can cause the symptoms of hay fever, and experimental evidence was presented to confirm the fact that it was the odor and not the pollen that produced the symptoms. Thus, instead of pollen, volatile agents from trees, flowers, grass, and weeds may be the cause of allergic symptoms and may produce their effects in any season.

Horesh[115] found it impossible to prove whether allergy is due to the odiferous substances from animal dander or to some other volatile agent. A certain number of his patients insisted that they were not bothered by all dogs but only those that "smell doggy." DeBesche[55] studied this subject by conducting experiments with the odorous substance in horse urine. He was able to produce asthmatic attacks in patients allergic to horses with this odorous substance under circumstances in which horse hair and horse dandruff were carefully excluded. DeBesche believed that volatile allergens other than dander and hair were responsible for some attacks of asthma suffered by persons sensitive to horses or other animals. He reported patients with allergic symptoms caused by the odors from cattle, dogs, cats, monkeys, sheep, goats, hares, rabbits, guinea pigs, rats, mice, hens, bees, toads, and eels. DeBesche accepted the possibility that the dander of animals is the most important carrier of the offending antigen, but believed that the odor of animals is also an etiological factor. Many persons with asthma caused by sensitivity to horses, according to DeBesche, have asserted that it is the odor of the horse which is the crucial factor, and it was sufficient to come into the presence of a person who "smells horsey" to provoke an attack.

Horesh[115] cautions that psychological factors can incite allergic symptoms, but he believes that psychic causes of allergic upsets should be accepted only after all other factors have been considered and excluded. Many so-called psychic causes for allergic upsets have vanished when odorous substances have been carefully evaluated.

### 2.1.3 Theories of Olfaction

Since 1870, about 30 theories have been proposed to explain olfaction; an excellent summary up to 1967 has been presented by Moncrieff.[190] These theories are summarized in Table 18, Appendix B. They are based on experimental correlation of odor with such physical and chemical properties as ultraviolet absorption, infrared absorption, Raman shifts, unsaturation, functional grouping, solubility in lipid, solubility in water, volatility, adsorption, oxidizability, and dipole moments. The greatest controversy is whether molecules of the odorant must come in contact with the olfactory receptors or whether the odorants emit waves which stimulate the receptors.[234] Thus, the numerous theories can be grouped into wave theories and contact theories.

Wave Theories. These theories are based on the fact that olfaction can occur at a distance from the odorous substance, and hence the molecules are assumed to emit radiation which travels to the olfactory receptors. These theories contradict two well-established characteristics of odor: namely, that to be odorous a substance must be volatile and that odor cannot travel where air cannot.

The theory of Beck and Miles[178] deserves individual mention because of its novelty. Essentially this theory proposed that the olfactory apparatus was a tiny infrared spectrophotometer, emitting infrared radiation and measuring its absorption by molecules near it.

Roderick[234] maintains that contact of the odorant molecules with the olfactory receptors is definitely required, and therefore, all of the no-contact or wave theories may be rejected. However, he cautions that investigations should include the effects of radiation on the olfactory apparatus, since rats can detect X-rays by means of the olfactory apparatus.[120]

Contact Theories. Contact theories assume contact of odorant molecules with the olfactory receptors. Roderick[234] has divided these theories into two subgroups based on whether the contacting molecule is thought to stimulate the olfactory receptors by chemical or physical means. The theories involving chemical interaction are mainly ones based on correlations with functional groups. These chemical theories were popular from 1900 to 1920, the period during which data on structure-odor were first being collected. But by 1930 there were sufficient data to establish that there is no simple relation of odor to molecular structure. Moncrieff[190] and Dyson[69] showed that compounds of very similar structure may have different odors, and compounds of very different structures may have similar odors. For example, the odor of macrocyclic compounds was shown to depend more on ring size than on functional groups, the odor of benzene derivatives depended more on the position of substituents than on their nature, and similar stereoisomers were found to have different odors.

From 1950 on, the major theories proposed recognized that the odor of a molecule could not be directly related to its functional groups but must be related to the molecule as a whole: i.e., odor is a "whole-molecule" property.[110] Beets[24] proposed in 1957 a profile-functional group theory in which odor was determined by two factors: the functional group with the highest hydration tendency determines the orientation of the molecule at the receptor, and the overall form or profile of the molecule also has some effect, which has not been specified.

The two major theories based on odor as a whole-molecule effect are discussed in Appendix C. These are the Dyson-Wright vibrational theory and the Moncrieff-Amoore stereochemical theory. These two theories appear to be the only significant theories today, and much of the current literature on theories of olfaction consists of a duel between them.[234]

### 2.2 Effects on Animals

### 2.2.1 Commercial and Domestic Animals

No information on the effect of odor air pollution on the health and behavior of commercial and domestic animals was found in the literature reviewed. However, there is considerable attention given to the sensitivity of the noses of mammals--particularly of dogs--[169,190] but these studies do not relate to air pollution.

### 2.2.2 Experimental Animals

No information was found on the effect of odor air pollution on the health and behavior of experimental animals. McCord and Witheridge[170] point out that it is impossible to determine whether certain odors are repulsive to rats. The investigators suggest that if left to their own devices, rats might choose a dunghill in which to nest.

### 2.3 Effects on Plants

Odors *per se* have no known effects on plants. However, many odorous compounds such as sulfur dioxide, ethylene, and ammonia are phytotoxic. The effects on the plants are due to toxicity rather than to odor.

## 2.4 Effects on Materials

Molos[183] reported that obnoxious fishy odors emitted from a soap plant adhered to skin, hair, clothing, automobiles, and other materials for extended periods of time. People who had been in or near the plant could smell the odors miles away for many hours. Clothing required laundering or dry cleaning to completely remove the odor.

## 2.5 Environmental Air Standards

Stern[260] has listed air quality standards for approximately 100 odorants. Industrial standards for another 250 specific odorants have been listed by the American Conference of Governmental Industrial Hygienists.[46] Air quality standards for these odorous pollutants are based on toxicity rather than odor of the pollutants, and have not, therefore, been included in this report.

Some State, county, and city regulations have tried to limit odor pollution on the basis that air contaminants unreasonably interfere with the comfortable enjoyment of life or property. Those States which list odors specifically as an air pollutant are the following:[23,178]

- Alaska
- Arizona
- California
- Florida
  - Duval County
  - Lake County
- Florida
  - Seminole County
  - Manatee County
  - Hillsborough County
  - Orange County

Hawaii
Iowa
Kansas
Maine
Maryland
Massachusetts
Michigan
Montana
New Hampshire
Ohio
Oregon
Rhode Island
Texas
Washington
Wisconsin

Some States, such as California, have been more aggressive than others in their action to control emissions of odorous compounds. The following California standard[39] for diesel odors and irritation exemplifies this fact:

> (a) The average intensity of odor as determined by subjective appraisal shall be less than the intensity from diesel vehicles with horizontal exhaust pipes representative of the diesels in use in 1966 and whose odorant concentrations have been reduced by at least 80 percent.
>
> (b) There shall be no detectable eye, nasal, or throat irritation to at least 75 percent of the panel.
>
> (c) Exhaust odors that are different in quality from characteristic diesel odor shall be less objectionable to the panel than the odor from diesel vehicles with horizontal exhaust pipes representative of the diesels in use in 1966 and whose odorant concentrations have been reduced by at least 80 percent.
>
> (d) The conditions for appraisal are:
>
> 1. The odor irritation panel shall consist of not less than 10 persons.
>
> 2. Appraisal of odor and irritation shall be made on a vertical plane ten feet distant from the exhaust outlet to either side of the motor vehicle parallel to the longitudinal axis. For vehicles with more than one exhaust outlet, the appraisal shall be made on a vertical plane parallel to the

longitudinal axis at a horizontal distance ten feet from the midpoint of the exhaust outlets.

3. The exhaust gas shall be evaluated during the modes of idle and full throttle acceleration.

4. Other methods of odor appraisal or measurement may be used if approved by the Department of Public Health.

In addition, the Los Angeles County Air Pollution Control District[51] has several rules which limit the emission of odorous compounds:

Rule 51 limits discharge of any air contaminants which cause "injury, detriment, nuisance, or annoyance."

Rule 52 limits the discharge of particulate matter.

Rule 53 limits the discharge of sulfur dioxide.

Rules 56,59,63, and 65 limit the discharge of gasoline, petroleum distillate, and petroleum products.

Rule 58 provides for proper incineration.

Rule 62 limits the discharge of hydrogen sulfide from burning fuels.

Rule 64 limits emissions from animal rendering plants.

Rule 66 limits emissions from evaporating solvents and other organic liquids.

## 3. SOURCES

The most frequently reported sources of obnoxious odors in the ambient air were listed in 1958 by Kerka and Kaiser.[143] These are tabulated in Table 19, Appendix B. In New York State, Hilleboe[108] reported the number of odor sources along with other contaminants. In cities with populations over 5,000, the number of nonindustrial sources of odors (77) exceeded the industrial sources (26). In smaller communities (less than 5,000) the number of nonindustrial sources (17) was less than the number of industrial sources (23), as shown in Table 20, Appendix B.

In 1955, the chief public officials responsible for control of air pollution in 67 major cities were surveyed.[211] The results of the survey showed that 78 percent received complaints of odors separately from other air pollution complaints, and 68 percent felt the public interest was increasing because of odor pollution. When asked to list the source of the odors in their communities, their replies were as follows:

| Source | Percent* |
|---|---|
| Chemicals | 62 |
| Vehicles | 52 |
| Paint and varnish | 49 |

---

*Percent of questionnaires in which the source was cited.

| | |
|---|---|
| Food processing | 47 |
| Domestic (homes, etc.) | 45 |
| Rendering plants | 43 |
| Plastics | 33 |
| Oil refineries | 31 |
| Coke works | 31 |
| Rubber | 27 |
| Steel | 25 |
| Insulation | 21 |
| Fish | 21 |
| Gas works | 19 |
| Pharmaceuticals | 19 |
| Soaps and detergents | 17 |
| Breweries | 15 |

The odor pollution of an area depends on the odor strength and quality. The odor unit has been defined thus: one odor unit is the amount of odorant necessary to contaminate one cubic foot of clean air to the odor threshold. For any one odorant, the number of odor units can be calculated by knowing the volume of odor released and the odor threshold. For example, dimethyl amine has an odor threshold of approximately 0.5 ppm (1,000 $\mu g/m^3$). A release of 10 pounds of this substance per hour would result in the release of 2,800,000 odor units per minute.[37] This number can then be used in atmospheric diffusion equations to calculate the distance the odor may travel. Any value above one would be detectable. Similar calculations are also useful to engineers in designing systems which will avoid or abate odor pollution. This method has been used by Benforado _et al._[26] for the various applications shown in Table 21, Appendix B.

The mixture of two or more odorants may present complicating factors because the odorants may be additive, synergistic, counteractant, or independent.

## 3.1 Natural Occurrence

Odors are produced in nature primarily from the decomposition of proteinaceous material (vegetable and animal) by bacterial action.[192,212] They develop principally in stagnant and insufficiently aerated water--for example, in swamps and polluted stagnant water.[58,64,212] Odors from these sources, variously described as fishy, aromatic, grassy, and septic, have been reported most often after the peak of the blue-gree algae concentration has passed.[132,173] Dimethyl sulfide and methyl mercaptan either together or separately have been found among the volatile constituents of certain green, brown, and red algae.[132] Methyl sulfide has been found in marine algae; methyl mercaptan has been an odorant of algae; and dimethyl sulfide has been found in certain seaweeds. Microscopic animals also produce odorous compounds. Collins and Gains[47] reported that hydrogen sulfide was one of the odorous constituents of actinomycetes. As a result, the odors emanating from contaminated waters, including the oceans, are usually offensive. These odors may often be accompanied with the offensive odors of dead fish found on the public beaches. Such an incident occurred in the Los Angeles area in 1964. Ocean water temperatures remained high (greater than 70°F) for several days, causing the "red tide" (plankton) to grow rapidly, thus creating a condition lethal to fish. Millions of fish washed onto the beaches, producing a stench along several miles of public beach. As a result, no people visited the beach for several weeks.

Robinson and Robbins[233] have estimated the annual worldwide production of some odorants. Hydrogen sulfide production in the middle sixties was about 90 to 100 million tons, with 60 to 80 million tons coming from land sources and 30 million tons from ocean areas. Other estimates of these figures ranged as high as 202 million tons from ocean areas and 82 million tons from land areas.[233] Data on background air concentrations of hydrogen sulfide arising from natural sources are scarce. However, concentrations, estimated to be between 0.15 and 0.46 $\mu g/m^3$, are below the odor threshold, or concentrations at which deleterious effects occur. Ammonia is also produced in large quantities by the biological processes,[233] mostly degradation of organic wastes. Approximately $3.7 \times 10^9$ tons of ammonia are released into the atmosphere annually.[85] Of this amount, only $4.2 \times 10^6$ tons are emitted to the atmosphere as a result of industrial and urban processes.

Many kinds of fires--such as forest fires, brush fires, and open field burning--also contribute odorants to the environmental air.

The human body is also a source of unpleasant odors. Body odors have been studied extensively by the United States Armed Forces.[282] Some typical odorants collected on charcoal during a 30-day human experiment are given in Table 22, Appendix B.

## 3.2 Production Sources

Odorants are produced as by-products (usually unwanted) in many industrial processes. Odorants are emitted during normal operations in the petroleum industry (refineries and natural gas plants), petrochemical plant complexes, chemical plants, coke-oven plants, kraft paper mills, chemical processing industry, dye manufacture, viscose rayon manufacture, sulfur production, manufacture of sulfur-containing chemicals, iron and metal smelters, cement plants, fertilizer plants, food processing plants, rendering plants, and tanneries.

### 3.2.1 Petroleum Industry

The stench of crude oil is evident near oil wells, petroleum refineries, and in recent months, the Santa Barbara Beach in California (which was contaminated from an offshore oil well leak).

The main sources of odor pollution in refineries are untreated gas stream leaks, vapors from crude oil and raw distillates, and fumes from process and condensate sewers.[214] The odorous emissions may contain hydrogen sulfide, mercaptans, phenolic compounds and naphthenic acids, organic sulfides, organic amines, aldehydes, and aliphatic or aromatic compounds.

The Petroleum Committee for the Air Pollution Control Association[214] has listed the potential sources of odorous compounds in a refinery as shown in Table 23, Appendix B.

Typical refinery processing systems that produce malodorous emissions are cracking units, catalytic reforming units,[177] and sulfur recovery units.[291] The cracking process tends to convert the sulfur contained in crude oil into hydrogen sulfide in the heavier materials and mercaptans in the gasoline fractions.[294] Measurements made in the El Paso, Tex., area adjacent to an oil refinery showed the mean hydrogen sulfide concentration to be 6 $\mu g/m^3$. The concentration varied from amounts too low to measure to a maximum of 91 $\mu g/m^3$.[5]

The main source of ammonia in oil refineries is from the catalyst regenerators in the catalytic cracking plants. The ammonia releases from oil refineries range up to 54 pounds per 100 barrels of feed.[17]

The ammonia emission from regenerator stacks in catalytic cracking units of Los Angeles area refineries was 4.2 tons per day from fluid bed cracking units and 0.2 tons per day from thermofor units.[17] At the time the data were compiled, there were 18 refineries in the Los Angeles area with a combined capacity of 700,000 barrels of crude oil per day.

In 1960 there were approximately 300 refineries distributed throughout the United States with a crude oil capacity of approximately 10 million barrels per day.[38] By 1969 there were about 263 refineries in the United States with a crude oil capacity of approximately 12 million barrels per day.[273] The States in which the refineries are located and their crude charge capacity in January 1969 are shown in Table 24, Appendix B. The crude capacity of refineries in the United States increased about 10 percent in the three years 1967 to 1969, and it is projected to increase another 10 percent in the next three years (1970 to 1972).[205]

The 14 oil refineries in Oklahoma were reported to cause air pollution problems of smoke, soot, and odors in 11 communities.[170]

Kropp and Simonsen[150] have reported odorous problems arising from fatty acids during grease-making processes, from vapor in asphalt production, and from sulfur oxides in acid treatment of lubricating oil. Mel'ster[176] also reported odor problems arising from asphalt production.

A common method of control of odorous emissions from petroleum plants is combustion of the waste gas. The combustion process oxidizes malodorous sulfides and amines to sulfur oxides and nitrogen oxides, which are also odorants but have a higher threshold odor concentration. Incomplete combustion results in odorous aldehydes.

A number of refineries and natural gas plants have installed units to recover sulfur from hydrogen sulfide. Sulfur plant installed capacities and yearly production rates are shown in Table 25, Appendix B.

Malodorous hydrogen sulfide occurs naturally in many areas associated with natural gas.[212] In some areas--for instance, Alberta, Canada--the sour natural gas can consist of over 50 percent hydrogen sulfide. The natural gas stream is treated to remove the hydrogen sulfide, which is generally converted to sulfur. Distributing companies which sell natural gas for heating and power generation generally require that its hydrogen sulfide content be less than 23,000 μg/m³.[249]

### 3.2.2 Petrochemical Plant Complexes

Malodorous gases are produced in petrochemical plants during cracking and other desulfurization reactions.[177] Krasovitskaya et al.[146] reported on atmospheric hydrogen sulfide concentrations around a petrochemical industrial complex in Russia. The complex consisted of three oil refineries, a synthetic alcohol plant, a chemical plant, and three power plants. Measurements in the industrial complex showed a concentration of 17 to 150 μg/m³ of hydrogen sulfide; 2.5 km from the complex it was 8 to 70 μg/m³; and 20 km from the complex it was 1 to 50 μg/m³.

### 3.2.3 Chemical Industry

Odorous compounds are products of many chemical operations. In general, they are formed when nitrogen or sulfur compounds are associated with organic materials at high temperatures. In many operations the end products have a highly offensive odor (e.g., carbon disulfide, pyridine, and thiophene).

Sources of malodorants in the chemical industry are the manufacture of sulfur dyes[165] and the production of viscose rayon, neoprene,[139] ethyl and methyl parathion (pesticides),[269] organic thiophosphate,[175] ammonia, aldehydes, and many other organic chemicals. Approximately 6 tons of hydrogen sulfide are formed for every 100 tons of viscose rayon produced.[192] Inorganic processes which evolve malodorous compounds include the manufacture of barium chloride (from barium sulfide), phosphorus compounds, pigments, lithopone, and sodium sulfide. Hydrogen sulfide is emitted during the manufacture of stove clay and glass.[142,212]

An odor problem in a soap plant was reported by Molos.[183] Amine-like (fishy) odors were produced in unknown areas in the plant. These obnoxious odors resulted in frequent complaints from plant neighbors and were often detectable 5 to 6 miles from the plant. Although the actual source within the plant was never located, continued public pressure, picketing, and two public hearings forced the company to install odor controls on storage tanks, and a centrifuging operation, and to revise the exhaust system, including the spray tower dryer.

Byrd _et_ _al._[37] reported an odor problem involving dimethylamine in a synthetic detergent plant. No quantitative data were given.

### 3.2.4 Pulp and Paper Mills

Hydrogen sulfide, mercaptans, organic sulfides, and organic disulfides are produced and released into the atmosphere in a number of processes in kraft pulp mills. Emission of such substances as these imparts the characteristic "rotten cabbage" or "rotten egg" odor in the vicinity of kraft paper mills and has been the cause of major air pollution problems. Over 50 percent of the pulp produced in the United States comes from the kraft or sulfate process.[141] Robinson and Robbins[233] estimated that in 1960, hydrogen sulfide emission from kraft paper mills throughout the world was about 64,000 tons.

In the kraft process, wood chips and a solution of sodium sulfide and sodium hydroxide (white liquor) are cooked in a digester for about 3 hours at elevated temperatures and pressures. The solution dissolves the liquor from the wood. The spent liquor (black liquor) is then separated from the cellulose fiber in the blow tank, after which the fiber is washed and processed into paper. The remainder of the process involves the recovery and regeneration of the cooking chemicals from the black liquor. The recovery process is initiated by concentrating the black liquor by evaporation. When the concentrated black liquor is burned in the recovery furnace, the inorganic chemicals collect on the floor of the furnace in a molten state (smelt).

Hot combustion gases from the recovery furnace are used in the direct contact evaporation to concentrate the black liquor. The smelt is removed from the recovery furnace, dissolved in the dissolving tank (where calcium hydroxide is added to convert the smelt from sodium carbonate to calcium hydroxide), and pumped to the causticizer, where the sodium carbonate is converted to sodium hydroxide by calcium hydroxide. The effluent liquor (white liquor) is used as feed to the digester. The precipitated calcium carbonate is then heated in a kiln to convert it to calcium oxide. The oxide is then slaked to calcium hydroxide for reuse in the causticizer.[141,260]

The major sources of odorant emission in kraft mills are the stack gases from the recovery furnace, including the direct contact evaporator; the stack gases from the lime kilns; and the noncondensibles from the digester relief, the blow tank, and the multieffect evaporator.[25,268] The concentration of odorous emissions from each source is given in Table 26, Appendix B. According to Sableski[242] investigations at the University of California have shown that 80 percent of the total gaseous sulfur appears as hydrogen sulfide and methyl mercaptan. The amount of these emissions that actually reaches the environment depends upon the efficiency of each of the abatement systems that are installed and operating at each mill. Table 27, Appendix B, shows the emissions from a kraft mill in Lewiston, Idaho. The mill produces 450 tons per day of bleached paper board and 200 tons per day of market pulp.[268]

The single largest source of odorants in a kraft mill is the recovery furnace, and the amount of odor produced depends upon furnace loading. The hydrogen sulfide produced in the furnace rises very rapidly when the furnace is operated above design conditions.

During a 6-month period in 1961 and 1962, surveys were made of ambient odors in the Lewiston-Clarkston area, where the paper mill is the major contributor of gaseous pollutants.[42] The results are shown in Tables 28-29, Appendix B. During an incident in November 1961, peak 2-hour concentrations of 77 $\mu g/m^3$ of hydrogen sulfide were measured.

In 1957, about 12.8 million tons of pulp were made by the kraft process; the location of these kraft mills is shown in Figure 2, Appendix A. The United States production of pulp by the kraft process from the year 1957 to 1967 is shown in Table 30, Appendix B.

Sableski[242] reported in 1967 on government-funded research on kraft mill pollution. Research at the University of California has shown that pulping hardwoods produces more methyl mercaptan and dimethyl sulfide than pulping soft woods and that methyl mercaptan is a primary product of pulp digestion. The mercaptan is partly consumed in the formation of dimethyl sulfide. At that time, the University of Washington was studying the kinetics of odor formation in the kraft process. A joint report from the Universities of Washington and Maine concluded thus:

(1) Although cooking soft woods at elevated temperatures for a short period of time reduces the amount of dimethyl sulfide formed as compared to cooking at lower temperatures for a longer period of time, it does not appreciably reduce the amount of the more obnoxious methyl mercaptan formed. Furthermore, any inadvertent lengthening of pulping times increases odors.

(2) The higher the sulfidity of the cooking liquors, the larger the amount of odorous compounds formed. Sulfidity should, therefore, be kept at the minimum practical for effective pulping.

(3) Recycling black liquor to the digester results in increased odor production, and this practice should be minimized.

(4) During the blow, the pH of the cooking liquor should not be allowed to drop below 12 in order to retain mercaptans and to reduce, by as much as 90 percent, hydrogen sulfide losses.

### 3.2.5 Coke Ovens and Coal

In 1966 about 66 million tons of coke, valued at $1,144,000 were produced per year in the United States in 66 coke oven plants.

Malodorants are produced in the coking operation. The effluent gas from coke ovens contains about 5,000 to 13,000 $\mu g/m^3$ of hydrogen sulfide (or about 6.7 pounds per ton of coal charged).[145] During cooling and scrubbing, approximately 50 percent of the hydrogen sulfide is removed. The remaining gas is either used as is for firing the coke ovens, purified further (partially desulfurized) and used for firing of coke ovens, or completely desulfurized and used for municipal gas.

Odorous emissions can occur throughout the complete coking cycle from coke-oven charging to hydrogen sulfide removal (desulfurization).[231] The sources of these emissions, other than charging and discharging emissions, and their causes are shown in Table 31, Appendix B. No data were found on the magnitude of odorant concentrations in the atmosphere in or around coke ovens. However, it is often of sufficient magnitude to create problems or evoke complaints from nearby residents.[171]

Coal refuse piles have been burning and causing odor pollution since coal mining first started.[274] Approximately

20 to 50 percent of the raw anthracite processed in cleaning plants is rejected as refuse. At many operations the refuse discarded amounts to about 33 percent of the tonnage produced. This refuse over the years has accumulated in coal refuse piles, some of which contain millions of tons.[260] The piles ignite either through spontaneous combustion, carelessness, or deliberate action. A recent survey indicated that there are approximately 500 burning piles in 15 States.[260] The odorants generated during combustion emanate from the piles and disperse into the atmosphere. Significant concentrations of hydrogen sulfide gas have been measured in communities adjacent to burning piles. Sussman[274] reported that hydrogen sulfide measurements made in July 1960 adjacent to a large burning anthracite refuse pile showed an hourly maximum average of 600 $\mu g/m^3$. The minimum hourly average was 140 $\mu g/m^3$.

### 3.2.6 Iron-Steel Industry and Foundries

Malodorants are given off in many metallurgical processes.[248] Wohlbier and Rengstorff[303] showed by experiments that the amount of hydrogen sulfide formed in slag granulation is proportional to the amount of hydrogen formed during the quenching process. Typical hydrogen sulfide exhaust emissions from foundries range from 4 to 100 pounds per 500 tons of castings produced per day.

### 3.2.7 Food Processing

Odors from food processing evoke frequent complaints. Food processing includes operations such as slaughtering, smoking, drying, cooking, baking, frying, boiling, dehydrating, hydrogenating, fermenting, distilling, curing, ripening, roasting, broiling, barbecuing, canning, freezing, enriching, and packaging. Some of these processes produce very obnoxious odors, while others produce quite pleasant odors. Because of the odor problems associated with meat processing, it is discussed separately.

McHard and Wromble[171] reported in 1965 that 538 manufacturing establishments in Oklahoma were processing food and related products. Odors from these processes and septic sewage resulting from plant operations caused the chief air pollution problems.

In South Dakota, 24 of 32 air pollution appraisal questionnaires mentioned food processing odors as sources of air pollution. Complaints included odors from milk and cheese processing, livestock pens, alfalfa dehydration, and grain elevators.[41]

Coffee processing produces four types of emissions: dust, chaff, odor, and smoke. The odor and smoke are combinations of organic constituents volatilized at roasting temperatures. Coffee roasting odors are attributed to alcohols, aldehydes, organic acids, and nitrogen and sulfur compounds. During decaffeination, odors can be traced to trichloroethylene, the solvent used in extracting caffeine from the green coffee beans. The odor-laden smoke presents the most difficult problem in emission control.[210]

### 3.2.8 Meat Industry

#### 3.2.8.1 Feedlots

The keeping of cattle, sheep, hogs, and poultry in feedlots often produces a noxious odor problem. Feeding on farms may produce odor problems, but the number of people affected is relatively small. Commercial feeding produces odors on a much larger scale, since a community may surround the feedlots.

According to Faith,[78,260] 10 million cattle are on feed in the United States. Commercial feedlots may contain 3,200 to 32,000 head during peak seasons. These cattle are normally kept on feed for 150 days, during which each animal eats 25 pounds of balanced ration every day. The animal will gain about 1 pound for each 8 to 10 pounds of feed. A 1,000-pound animal will produce approximately 26 pounds of total excreta per day, 15 pounds of which is urine. Thus a large potential for odor pollution exists where many animals are kept.

Odor problems develop in two ways.[260] One is the typical range odor of fresh excreta. The odor is rapidly dissipated as the excrement cools. This odor is not particularly offensive. If the manure remains wet, a second and more offensive odor develops as the bacteria multiply rapidly and putrefaction begins. Such highly odorous substances are produced as ammonia, hydrogen sulfide, and organic amines. These odors may be confined in manure piles where a crust has formed and will not be released until the crust is broken, usually during manure removal.

Similar problems arise in feedlots for hogs, sheep, and poultry (usually in egg production). In one instance, the urine and droppings were collected underneath the slotted floor of a pigsty, and the manure was agitated prior to removal. This agitation allowed malodorous gases to escape, and within an hour all the pigs lay dead in their pens.[53]

The physical conditions which cause odor problems in feedlots have been listed by Moorman[193] as these:

(1) Poor drainage allowing water or wet manure to stand for long periods of time.

(2) Spilled feed from feed trucks or around feed mills.

(3) Improper carcass disposal.

(4) Accumulation of manure in feeding pens.

(5) Improper management of manure disposal operations.

### 3.2.8.2 Livestock Slaughtering

Slaughtering operations have traditionally been associated with odorous air contaminants, though many odorants are due to by-product operations rather than to slaughtering and meat dressing itself. Slaughtering is considered to include only the killing of the animal and the separation of the carcass into edible meat and inedible by-products.

Cattle-, sheep-, and hog-killing operations are necessarily more extensive than those concerned with poultry, though poultry houses usually handle appreciably larger numbers of animals.

In the slaughtering operation, the animal is stunned, bled, skinned, eviscerated, and trimmed. Blood is drained and collected in a holding tank. Entrails are removed, sliced in a "gut hasher," and washed to separate the partially digested food, termed "paunch manure." Many slaughterers have heated reduction facilities in which blood, intestines, bones, and other inedible materials are processed to recover tallow, fertilizer, and animal feeds. Other slaughterers usually sell their offal to scavenger plants that deal exclusively in by-products. Hides are almost always shipped to leather-processing firms. Dressed beef, normally about 56 percent of the live weight, is refrigerated before it is shipped.

Odors emitted from slaughtering operations can be differentiated as (1) those released from the animal upon killing and cutting, and upon exposure of blood and flesh to air; and (2) those resulting from the decay of animal matter spilled on exposed surfaces or otherwise exposed to the atmosphere. Odors from the first source are not appreciable when healthy livestock are used. Where nuisance-causing odors are encountered from slaughtering, they are almost always attributable to inadequate sanitary measures. These odors probably result from breakdown of proteins. Amines and sulfur compounds are considered to be the most disagreeably odorous breakdown products.[51]

In addition to these sources, odors arise from slaughterhouse stockyards and from the storage of blood, intestines, hides, and paunch manure before their shipping or further processing.[51]

### 3.2.8.3 Inedible Rendering of Animal Matter

Animal matter not suitable as food for either humans or pets is nevertheless converted into salable products by rendering. Animal rendering plants are the principal outlets for disposal of wastes from slaughterers, butchers, poultry dressers, and other processors of flesh foods. In addition, rendering plants dispose of whole animals (such as cows, horses, sheep, poultry, dogs, and cats) that have died from natural or accidental causes. The principal products of the reduction processes are proteinaceous meals, which find primary use as poultry and livestock feeds, and tallow.

In the normal reduction process, the raw animal materials are picked up from individual sources and trucked to the rendering plant, usually in open-bodied trucks with canvas covers. The raw material is dumped into a receiving bin, from which it is conveyed to a grinder (breaker) where the meat and bones are ground (hashed), and then conveyed to the cooker. The cooker is either a steam-jacketed vessel (dry-rendering process) or live-steam-heated vessel (wet-rendering process). The cooker may handle from 6,000 to 12,000 pounds of raw material in batch processes, and some may handle as much as 40,000 pounds. More recently built plants use a continuous process. Temperatures of 300°F are required to digest bones, hooves, hides, and hair. Process times range from 1 to 4 hours. Most of the moisture is evaporated and exhausted from the cooker. This exhaust steam contains extremely odorous gases. Tallow is drained and pressed from the cooked meal. The tallow is then filtered and further dehydrated by centrifuging, settling, or air blowing.[293]

Some materials, such as blood and feathers, that do not contain tallow are also digested and dehydrated in dry-rendering cookers.

Malodors are the principal complaint around rendering plants. These odors arise mainly from the raw materials (especially during the grinding operation), cooker drier, percolator, and press.[277] Many factors may significantly influence the offensiveness and quantity of odors:[126]

(1) The age and condition of raw material.

(2) Overcooking.

(3) Overheating the drier.

(4) Excess air flow through the drier.

(5) Inadequate control equipment.

(6) Overtaxing the capacity of condensers and scrubbers.

(7) Improper disposal and inadequate treatment of liquid wastes.

(8) Insufficient temperature or residence time in incinerator.

(9) Poor housekeeping.

(10) Failure to collect all emissions for deodorization before release to the atmosphere.

Summer[272] stresses that once the carcass is fly-blown and maggot-infested, the obnoxious trimethylamine is produced rapidly. Chemicals which are responsible for the offensive odors have been reported by Strauss[265] and Ronald[235] as ammonia, monoethylamine, diethylamine, triethylamine, hydrogen sulfide, and in lesser quantities skatole, other amines, sulfides, and mercaptans. Aldehydes and organic acids are derived from fats. Putrescine, $NH_2(CH_2)_4NH_2$, and cadaverine, $NH_2(CH_2)_5NH_2$, are two extremely offensive odorants associated with decaying flesh.

The odor concentration and production rate have been measured in rendering plants. These data are shown in Table 32, Appendix B. Mills et al.[179] have estimated the odor emissions in the Los Angeles Metropolitan Area for 1966 from rendering refuse from beef cattle. The average cattle kill was 28,000 per week. He assumed that 15 percent offal and 5.5 percent raw blood were derived from an average 1,000-pound steer. He calculated that rendering plants would produce $3.15 \times 10^{11}$ odor units per day from offal and $5.24 \times 10^{11}$ odor units per day from blood. The figures show that the 26 percent of blood of the total rendered material produced 62 percent of total quantity of odorants. The total quantity of odorants was $8.39 \times 10^{11}$ odor units per day. He points out that he did not include swine, sheep, poultry, or horses in his calculations, and also that the odor emissions would have been considerably higher if the offal and blood had been allowed to putrefy.

Mills *et al.*[179] have also reported that most odor emissions take place during the first hour of cooking in the batch process. Their results are summarized in Figure 3, Appendix A. However, the emission rate depends largely on the operating mode. The above data are for a system operating at ambient pressure. In a system operating under vacuum or pressure, the odor would be emitted faster or slower depending on the mode. On the other hand, a continuous system would have a continuous emission of odors.[51]

### 3.2.8.4 Fish Processing

In the fishing industry, odors are unavoidable because of the nature of the species. Objectionable odors can be detected in fishing wharfs, canneries, and reduction plants. Heavy odor emissions that cause nuisance complaints can usually be traced to poor sanitation. Trimethylamine is the principal compound identified with fish odors.[51]

Reduction of inedible wastes from fish to fish meal is carried out in about the same manner as the animal rendering process described above. This reduction process is capable of producing large quantities of odorants. Mills et al.[179] have reported some typical odor emissions, which are presented in Table 33, Appendix B.

### 3.2.8.5 Edible Meats

Odors are also emitted from edible meat processing. However, compared to emissions from inedible-rendering processes, the odors from edible-rendering processes are relatively minor. In the Los Angeles area, only 10 percent of the total animal material rendered is from edible meat, and the rates of odor emissions are low. The concentration in the exhaust gas is only about 3,000 odor units per scf.* The main reason for this is that edible materials are kept scrupulously clean.[51]

### 3.2.8.6 Tanneries

Offensive odors often arise from tanneries. Summer[272] states that the main cause of these odors stems from skins which have become infested with maggots. Sinitsyna[251] claims that the air of tanneries becomes polluted with ammonia.

---

*scf-standard cubic foot.

### 3.2.9 Miscellaneous Production Sources

There are many other production sources of odors which may cause complaints. Some of these include the paint industry,[51] varnish kettle cookers,[51] wire reclamation,[51] electroplating,[294] cement production,[147] cotton ginning,[48] and breweries.[143]

## 3.3 Product Sources

Odorous product sources fall into four categories: perfumes and cosmetics, masking agents, counteracting agents, and warning agents. All of these products are purposely emitted into the air. Complaints have arisen only when the product is improperly used. Examples of improper use of masking agents and counteractants have been discussed in the previous section. Warning agents consist of small quantities of malodorous gases added to nonodorous lethal gases to warn people of gas leaks.

## 3.4 Other Sources

### 3.4.1 Combustion Processes

Odorants are released when wood, coal, oil, or gas are burned.[272] The quantity of odorant will depend upon the amount of sulfur in the fuel and the efficiency of the combustion process. In an efficient combustion system the hydrocarbons, sulfur, and nitrogen compounds will be oxidized to carbon dioxide, water, sulfur dioxide, and nitric oxide. However, if the combustion is incomplete, malodorants such as hydrogen sulfide and aldehydes are released.[272] In studies[8,238,253] of sulfur released from domestic boilers, hydrogen sulfide was found to be given off during heavy smoke emission, mainly just after refueling.

Williams[299] points out that the most frequent cause of odorant production in fuel-burning operations is incomplete combustion. This also produces smoke, and thus smoke and odors are often associated.

The tepee burner[73] is another source of odor complaints. Incineration of plastic products, garbage, and rubber products is accompanied by extensive and often nauseating odors.

Refuse burning is reported to be a common cause of odor complaints, both from open burning in garbage dumps and incineration.[171] Odors emitted from the incineration of refuse collected overnight in an apartment house were measured by Kaiser *et al.*[138] Their observations (tabulated in Table 34, Appendix B) showed emission concentrations of 2.5 to 100 odor units per cubic foot and emission rates of 4,900 to 145,000 odor units per minute.

Gasoline and automobile exhaust are frequent sources of odor complaints. Automobile exhaust odorants are not as offensive as diesel exhaust odors. Therefore, they have not been studied to the same extent as diesel odors. There are numerous studies on the emission of several individual odorants, such as aldehydes, sulfur oxides, and nitrogen oxides, but no studies were found on odors per se.

#### 3.4.1.1 Diesel Engine Odors

Exhaust constituents and odors have been related to aldehyde concentrations in diesel exhaust because aldehydes have a characteristic odor and cause irritation in exceedingly low concentrations. Table 35, Appendix B, shows the approximate relationships of total aldehyde concentrations to odor intensities of diesel exhaust as estimated from the results of three separate studies.[72,239,297]

Although each investigative group found a definite relationship of aldehydes to odor, the relationships differed somewhat. Much of the difference is due to the subjective evaluation methods and to the analytical procedures. In addition, the quality of odor may change with different fuels, engines, load and rpm, and other factors.[227]

Rounds and Pearsall[239] tested correlations of odors from diesel engines with formaldehyde, higher aldehydes, and oxides of nitrogen, as well as with total aldehydes. They found that formaldehyde and oxides of nitrogen did not correlate as well with odor as did total aldehydes. They concluded, "The concentrations of the exhaust gas constituents measured in the present study cannot be used to predict reliably the changes in odor or irritation intensity which would accompany changes in factors such as engine operating conditions, the engine design, the fuel, or the lubricant. Further, the data suggest either that constituents other than those measured are contributing significantly to odor and irritation or that the chemical methods used are not measuring accurately the constituents they are intended to measure."

The concentrations of acrolein, formaldehyde, and total aldehydes appear to be about the same from gasoline engines as from diesels,[73,119,121,156,239] thus indicating that other compounds must contribute to odor and irritation from diesels. Objectionable diesel odors have occurred at a time when aldehydes were present in the air only at extremely low concentrations.[72]

In another study,[156] the concentrations of nitrogen dioxide, formaldehyde, acrolein, and hydrocarbons in the diesel exhaust gases were compared with the odor threshold concentrations. The concentrations of nitrogen dioxide, hydrocarbons, acrolein, and formaldehyde present in the diesel exhaust at the threshold dilution (Table 36, Appendix B) show that (1) under the 1,600 rpm*, full-load condition, the average concentration of nitrogen dioxide present in the threshold dilution of diesel exhaust is 38 percent of the average threshold for pure nitrogen dioxide; (2) under the 500 rpm, no-load condition, the average concentration of nitrogen dioxide present in the threshold dilution of diesel exhaust is 51 percent of the average threshold for pure nitrogen dioxide; (3) for both types of exhaust, the average concentration of acrolein and formaldehyde present at the threshold dilution of the exhaust is only one-tenth to one-hundredth of the thresholds for the pure compounds; and (4) the average concentration of hydrocarbons at the threshold dilution of 500 rpm, no-load diesel exhaust is larger than for the 1,600 rpm, full-load exhaust. Tentative conclusions were as follows:

(1) At the odor threshold dilution of diesel exhaust, acrolein and formaldehyde were present in such small concentrations, in relation to the threshold concentration for the pure compounds, that it is unlikely that

---

*rpm: revolutions per minute.

they were major factors in the odor of diesel exhaust.

(2) Under load conditions, the amount of nitrogen dioxide present in the odor threshold dilution of diesel exhaust was large enough, in relation to the odor threshold for pure nitrogen dioxide, that nitrogen dioxide was more likely to be a major factor in the odor detectability of diesel exhaust than were acrolein and formaldehyde. The data in Table 37, Appendix B, support this conclusion.

(3) At ideal conditions, hydrocarbons, as measured by infrared carbon and hydrogen absorption, were present in such large concentrations in relation to nitrogen dioxide, acrolein, and formaldehyde, that the unburned diesel fuel was a likely suspect as the major factor in the odor of diesel exhaust produced under these conditions. The data in Table 38, Appendix B, support this conclusion.

A number of investigators have suggested that smoke or particulate matter also contributes to odor.[82,155,157,239] In one study, removal of smoke by filtration greatly reduced odor intensity, although electrostatic precipitation was ineffective in doing so.[239] In another study, particulate matter collected on glass fiber filters was extracted with benzene, and upon evaporation of the benzene, an oily yellow residue with a "heavy diesel odor" remained.[156]

Reckner *et al.*[227] observed that nearly all of the odor was removed from diesel exhaust when the gas was bubbled through a 5 percent aqueous sodium bicarbonate solution.

There is considerable evidence that the most pronounced and objectionable odors and the highest aldehyde concentrations in diesel exhausts occur at conditions of no load, idle, and deceleration or acceleration after idle.[27,72,297] These odors have been described as very pungent, sharp, acrid, and objectionable. Under load conditions, odors were strong and heavy but not particularly objectionable.[297] Berger and Artz[27] reported only faint odor when a diesel mine locomotive (GM 6-71) was operating upgrade under load. When the locomotive was descending the grade, considerable odor and eye irritation were evident. The high aldehyde and odor intensity may be caused by chilling of the combustion chamber and substances reacting with the great excess of air under no-load conditions.[27,72,232]

However, Rounds and Pearsall[239] found much higher concentrations of aldehydes at full load than at no load with a two-cycle engine. Concentrations were lowest at intermediate loads. The data indicated that diesel exhaust gas was most odorous and irritating at either no load or at full load. At intermediate loads the intensities were less, although this effect was not as pronounced with odors as with irritation. The effect of engine rpm was small compared to that of load.

Rounds and Pearsall[239] also compared the odor intensities produced by three different engine makes, a two-cycle and two four-cycle engines. They found that at intermediate loads, the odor intensities from all three engines were practically the same. At full load, one of the four-cycle engines had less odor than the other two, which had about the same odor intensities. At no load the other four-cycle engine had the least odor.

Another factor which influenced the odor production of diesel engines was the mechanical condition of the engine. Rounds and Pearsall[239] found that an engine in poor mechanical condition except for the fuel injection system produced slightly higher odor intensities, but only when partially loaded. The engine tested produced excessive smoke, which indicates that odor and smoke are not necessarily related. Roberts[232] indicates that leaking valves can reduce the temperature of the combustion chamber and increase smoke and odors. Leaking injectors or maladjusted governors increase aldehyde concentrations and probably also affect odor intensity.[111,239,297]

There are conflicting reports on the effects of fuel on odor. Reckner *et al.*[227] and Young[309] believe that a fuel produces two separate effects: odor and lacrimation. Furthermore, light diesel fuels, such as kerosenes, are satisfactory with respect to odor (and smoke), but the lacrimation effect may be greater than for fuels with higher boiling points. Reckner *et al.*[227] suggest that the differences they observed in odors of two unburned diesel fuels and the exhausts from burning these fuels might be explained by their differing volatility. Grunder[98] stated that city-type buses using kerosene-like fuel had a characteristic odor which is pungent, sometimes irritating to the eyes, and objectionable in heavy traffic to many people. He also stated that these buses introduced a distinctly different odor easily distinguishable from the odor from gasoline engines or four-cycle diesel engines operating on regular grade diesel fuel. According to Rounds and Pearsall,[239] the odor (and irritation) from a low endpoint fuel was only slightly more than from a high endpoint fuel (the cetane number and initial boiling points of the fuels were about the same). Roberts[232] thought that the highly volatile fractions in the diesel oil were prone to cause partially oxidized fuel in the exhaust gases.

A number of investigators have found that cetane number influences aldehyde concentrations and odor only during no-load conditions and immediately after: the lower the cetane number, the higher the aldehyde concentration.[72,239,297,309] With respect to odor, Wetmiller and Endsley[297] state that offensive odor depends only on cetane number. Young[309] says that cetane number has some bearing on odor; and Rounds and Pearsall[239] state that it has but a slight effect. Sinks[252] reported that no marked change in odor resulted from varying the volatility and cetane number of the fuel over a wide range. Additives or impurities may also affect the odor of diesel exhaust gases. Young states that the addition of amyl nitrate tends to improve exhaust odor by increasing cetane number, but may slightly increase the tendency for the eyes to water.[309] There is good evidence that high sulfur content fuels increase odor and irritation.[239,267]

Studies show that the oil type has no effect on odor intensity but does affect odor quality.[239,252] It was found that in all conditions, a polyalkane glycol oil produced more offensive exhaust odors than a mineral oil. At low speeds and loads, a diester oil gave a less offensive smelling exhaust gas than did the mineral oil, whereas at high speeds and loads the opposite was true.

The National Air Pollution Control Administration is presently funding diesel odor studies at the U.S. Bureau of Mines at Bartlesville, Okla.; the Southwest Research Institute at San Antonio, Tex.; and the A.D. Little Laboratory in cooperation with Illinois Institute of Technology.

### 3.4.1.2 Aircraft Odors

Lozano et al.[159] have reported the odor dilution threshold concentrations for jet aircraft. These data are summarized in Table 39, Appendix B. The authors point out that the odor dilution threshold concentration is highest for fan-jet engines at idle, and this concentration (1,000 odor units per scf) is approximately three times higher than diesel engine exhaust at idle. Conventional jets and turbojets were 10 to 100 times lower at idle than in the cruise and take-off mode.

A 10-day odor survey was conducted near the John F. Kennedy International Airport in New York[201] in 1964 (October 5th through 9th and October 19th through 23rd) to determine the major types of odors in the area, particularly those that can be attributed to jet aircraft exhaust. An untrained corps of odor observers was used, consisting of about 100 seventh- and eighth-grade science students residing in the study area. The students were tested for sensitivity by means of the "triangle" test, using odorant solutions of vanillin, methyl salicylate, and butyric acid. All students tested were found acceptable as observers. Students were instructed in the manner of making odor observations, and observations were made three times daily at 7 a.m., 4 p.m., and 8 p.m. Observers noted the strength of the odor, if observed, and described the odor in their own words on a data form provided. The data subsequently were punched onto cards and analyzed by use of a card sorter.

The number, type, and location of odor observations made are given in Table 40, Appendix B. All communities surveyed are within 3 miles of the airport. The greatest percentage of positive odor responses occurred in the Rosedale area (Zone 3), followed by South Ozone Park (Zone 4). No odors were described by the students as jet exhaust smoke or odor. To determine whether odors described as "gasoline and diesel engine exhaust" or "oily or fuel odor" could have possibly originated at the airport, these observations were compared with wind direction. Six of these observations were made at a time when odor originating at the airport could have been carried by wind to the observer, and 20 of these observations were made when odors from the airport were being carried away from the observer. These data indicated that gasoline and diesel exhaust and oily or fuel odors were not specifically related to jet aircraft emissions in this instance, and that sources other than the airport were the main contributors.

The possibility that emissions from jet aircraft do create an odor problem should not be ruled out. Odors from these sources may be apparent during other seasons of the year or during more adverse meteorological conditions.

### 3.4.2 Sewage

Complaints of odors have come from the immediate vicinity of some sewage treatment plants, especially during the summer months when the daytime temperatures are high and there is little or no air movement. In most cases, these odor problems are experienced only in areas immediately adjacent to sewage treatment plants[229,295] or open manholes.[229]

In Chicago, Ill., the sewer system in the city has been cited[229] as a frequent source of offensive odors emanating from manholes. Such problems are not unusual in communities where domestic sewage is discharged to a sewer system which was originally designed to carry off storm water. Since storm sewers normally handle large volumes of water over short time periods, they are laid on a grade less than that required for a system handling only domestic sewage. As a result, solid sewage deposits often remain in the sewer where they generate odors in the process of decomposition.[229]

Malodorous gases are produced biologically in sewers and treatment plants from organic compounds formed by hydrolysis of materials like cystine and methionine and by reduction of sulfates. A survey of odors emitted most frequently at some 300 sewage treatment plants in the U.S. shows that the methyl mercaptans, methyl sulfides, and amines are leading causes, followed by indoles and skatoles, and last of all the notorious hydrogen sulfide.[219] Factors that influence odorant generation in sewers include temperature, content, age, and pH value of sewage; flow velocity; and ventilation of the sewer.

In the Washington, D.C. metropolitan area about 1,000,000 cubic feet of sewage sludge gas is produced each day by various sewage treatment plants. This gas is used as fuel for certain types of engines or for heating purposes, or is wasted by flaring.[295] Atmospheric measurements made at a sewage treatment plant in El Paso, Tex., in 1958 showed that the hydrogen sulfide atmospheric concentration varied between 24 $\mu g/m^3$ and 2,120 $\mu g/m^3$, with the average concentration 610 $\mu g/m^3$. At a sampling station 100 yards from the sewage plant, the maximum hydrogen sulfide concentration was 205 $\mu g/m^3$.[5]

At the Stickney treatment plant in southwestern Chicago, a source of frequent odor complaint is believed to be the storing or disposal of sewage sludge in lagoons at the plant site on those occasions when the plant cannot use non-odor-producing processes.[229]

### 3.4.3 Miscellaneous Other Sources

Many other sources of odors may cause complaints, such as the use of fertilizers, insecticides, paint solvents, and other solvents.

A characteristic pungent odor is associated with photochemical smog. Ozone is the acrid component of this odor.[129]

## 3.5 Environmental Air Concentrations

No quantitative data have been reported on the odor concentration in ambient air even though a number of odor surveys have been made. These surveys have shown detectable disagreeable odors, but their intensity was not reported.

## 4. ABATEMENT

Odor abatement has been reviewed by Turk,[284] von Bergen,[292] and Summer.[272] The abatement methods employed depend largely on the odor-producing process, the odorant, and other substances in the waste gas stream. These abatement methods fall into several categories: combustion, absorption, adsorption, odor masking, odor counteraction, dilution, source elimination, particulate removal, chemical control, biological control, and containment. Often two or more of these processes may be combined to eliminate an odor problem.

Complete combustion is generally accepted as the best way to deodorize malodorous gases. However, it may not be the most economical method. Complete oxidation of odorants converts hydrocarbons to odorless carbon dioxide and water, and sulfur and nitrogen compounds to sulfur oxides and nitrogen oxides that usually have higher odor thresholds than the parent compounds. Partial oxidation may increase the odor problem by the formation of malodorous aldehydes.[292]

Oxidation at 1,200°F or above has been recommended and usually gives satisfactory results. The temperatures may be lower (500 to 800°F) when a catalyst is used. This will depend on the odorants and the possible catalytic poisons in the gas stream.[292]

Reed and Truitt[228] point out that the control of odors emitted from incinerators can take place either in the combustion chamber or in the stack just before release to the atmosphere. They propose an auxiliary gas burner with a flame temperature of at least 1,500°F.

Benforado[26] has reported on measurements of odor concentrations made before and after incineration in a number of plants. These results are tabulated in Tables 41 and 42, Appendix B.

Odor-laden smoke from the coffee roasting industry is most effectively controlled with afterburners, but fuel requirements are increased 100 to 150 percent over those for a conventional roaster.[210]

Where odorants are soluble in water or some other liquid or solution, absorption may be used. For example, ammonia may be removed by spraying water through a chamber containing the ammonia. Hundreds of methods have been devised for contact between vapor and liquid. Some of those used include simple vertical spray towers in single or multiple stages and cascade vertical towers packed with partition rings, Raschig rings, spiral rings, Berl saddles, hollow balls, helical packers, hexahelix blocks, double spirals, cyclohelix blocks, prismic packings, centrifugal or cyclone scrubbers, and bubble and sieve trays.[274]

Some solids will adsorb odorant compounds and thus remove them from the system. This process requires that adsorbent and odorant be matched. Activated charcoal has the particular advantage that it will adsorb all types of materials under almost any conditions. However, the efficiency of any adsorbent system is dependent on the temperature, pressure, and flow rate of the gas stream.[272]

Odor masking is the process of eliminating the perception of one odor or group of odors by superimposing another odor or group of odors on it to create a new odor sensation, preferably pleasant. Odor-masking chemicals are usually synthetic aromatic compounds or a mixture of these compounds.[292] Some examples of these are vanillin, methyl ionones, eugenols, benzyl acetate, phenyethyl alcohol, and heliotropin. The proper masking agent does not alter the composition of the preexisting odorant, but has a pleasant smell that is strong enough to overpower the offensive odorant.[272]

All smells cannot be masked. In particular, strong acids, even in traces, will defy masking because the agents used decompose under acid conditions.[272]

Masking agents may be applied directly to raw material (sewage, animal or vegetable waste, blood), drip-fed into process lines, added to scrubbing waters, injected into gas streams, soaked into covers for small leaks, or sprayed as a fog.[272]

The chief advantage of this method of control is that little or no capital costs are involved. Masking may be used as a temporary measure while other control methods are developed.[292] Odor counteractants are often used together with masking agents in a single application.[292]

The effect of odor counteraction is to reduce both the odor of the counteractant and the odor of the malodorant. When the two odors are sniffed together, both odors are diminished. This is often confused with odor masking, in which equal strengths of two odorants may both be distinguished and the masking agent concentration must be increased to overpower the malodors.[292]

Moncrieff[190] has cited the following examples of counteractant pairs:

Cedarwood and rubber
Wax and rubber
Wax and balsam of tolu
Paraffin and rubber
Rubber and balsam of tolu

When benzene, toluene, xylene, pseudo-cumene, and durene are mixed in small quantities, their odor strengths are additive. However, at higher concentrations, the odor becomes faint. Another example of counteraction is the pair, butyric acid and oil of juniper. When air is bubbled through a butyric acid solution, the characteristic strong, unpleasant odor is perceived. Oil of juniper also has an unpleasant odor, but a mixture of the vapors has a faintly pleasant odor.[190]

Odor dilution will obviously result in odor-free air as an odorant is diluted below the threshold concentration. Such a method is feasible to remove an odor problem from a plant area provided the weather conditions are favorable. However, unfavorable meteorological conditions may cause the odorant concentration to increase above the odor threshold. Thus, the odor emission rate (odor units per minute) must be weighed against the possibility of adverse meteorological conditions in order to prevent odor pollution.[272,292]

Another method of odor control is to eliminate or reduce the odor-producing substance. This type of control is being practiced by using low sulfur fuels.[272]

Many odorants are adsorbed on particulates, and the removal of these particulates may also reduce the odor.[49]

Chemical control of odors is possible in many industries. Chemical oxidation or combination may change an odorant to a nonodorous compound. Frequently, chlorine or potassium permanganate is added to a scrubbing solution to oxidize the odorants.[272] Other reactions result in ammonium acetate products that have no odor--for example, the reaction of acetic acid with ammonia which produces odorless ammonium acetate. Ozonation, catalytic chemical oxidation, silent electric discharge, and ultraviolet radiation will all result in chemical conversion of some odorants to compounds with a less offensive odor.[272]

Biological control may be possible in some operations. The biological degradation of sewage produces odorous gases. However, it is known that some microorganisms (_Beggiatoa alba_) oxidize hydrogen sulfide to water and sulfur, and this method has been suggested for sewage odor control.[272]

Containment offers a means of odor abatement in some situations. Covers on fuel tanks, sewage ponds, and other open storage areas will reduce the emissions of odor.[272]

## 4.1 Petroleum Industry

Odor pollution control methods used most frequently in the petroleum industry are scrubbing and combustion.[177,214] Mercaptans are often removed in alkaline scrubbers or converted to disulfides. Hydrogen sulfide is often treated with an amine (diethanolamine) in a scrubber. These malodorous gases may be recovered from the scrubber in a regeneration step for disposal by combustion in a waste gas furnace. Aldehydes do not present problems with proper incinerator temperature.[214]

Kropp and Simonsen[150] have described a fog-filter-type scrubber that was successful in removing fatty-acid odors, hydrogen sulfide, and sulfur dioxide.

## 4.2 Chemical Industry

Abatement of odors in the chemical industry depends entirely on the nature of the chemical process and the odorant, each group requiring a specific control.

Ilgenfritz *et al.*[122] of Dow Chemical Company emphasize that a large chemical complex such as their

Midland, Mich., operation requires continual surveillance by odor panels and immediate response to complaints. Response to complaints from in-plant personnel prevents out-of-plant complaints by a ratio of 14 to 1.

Sandomirsky *et al.*[244] reported on an "intolerable odorous fume condition" produced by a rubber processing plant (B. F. Goodrich Company). These odorants were non-soluble and, therefore, could not be removed with a scrubber. Incineration at 1,300°F was found to solve the problem. Tests at lower temperatures showed that satisfactory incineration was achieved at temperatures down to 1,100°F, but smoke and odor appeared as the temperature was lowered to 800°F. The 1,300°F incineration resulted in a concentration of 50 odor units per standard cubic foot, approximately 205,000 odor units per minute.

## 4.3 Pulp and Paper Mills

Sableski[243] has summarized the odor control methods for kraft mills as follows:

| Source | Methods of Control |
|---|---|
| Pulp digestion | Condensation of vapors followed by incineration |
| Multiple-effect evaporation | Condensation of vapors followed by scrubbing or incineration |

| Source | Methods of Control (Continued) |
|---|---|
| Direct-contact evaporators and recovery furnace | Black liquor oxidation accompanied by strict process control |
| Dissolving tank | Scrubbing |
| Condensate disposal | Stream stripping followed by incineration |
| Lime kilns | Improved mud washing and use of scrubbing fluids without sulfides |

The greatest reduction of odorant emissions was achieved by the black liquor oxidation process. The process consists of oxidizing the sulfides in the weak black liquor (before going through the multiple-effect evaporators) or strong black liquor (after going through the multiple-effect evaporators) by contacting it with air in a packed tower or thin film or porous plate black liquor oxidizing unit. The oxidation converts the sulfides to less volatile compounds which are less odorous and have less tendency to escape.[141] This has the effect of reducing the odorant emissions from the direct-contact evaporator and the recovery furnace stack by 80 to 95 percent.[104,140,151] The weak black liquor oxidizing process also reduces emission from the multiple-effect evaporators.

The majority of the black liquor oxidizing systems installed in the United States, which are based on oxidizing weak liquor, are located in the Western part of the country. In the South, the woods used in kraft processes cause excessive foaming problems in the weak black liquor oxidizing process.[151,207] To alleviate this, a few southern mills have installed an oxidizing process based on oxidizing the strong black liquor.[207,208]

The key to minimizing odorous emissions from the recovery furnace even in those systems employing black liquor oxidizing systems is proper furnace operating conditions. For minimum emissions from the recovery furnace the furnace should not be operated above design conditions. There should be 2 to 4 percent excess oxygen leaving the secondary burning zone (i.e., leaving the furnace), and there should be adequate mixing (turbulence) in the secondary combustion zone.

In the direct-contact evaporator, where flue gases from the recovery furnace are used to concentrate the black liquor, the carbon dioxide in the flue gases reacts with the sulfite in the black liquor to release hydrogen sulfide.[207] As noted before, this is substantially reduced by the black liquor oxidizing process. However, some sulfite remains even after the oxidation. Therefore, removal of the direct-contact evaporator from the stream would further reduce hydrogen sulfide emissions.[207]

To reduce recovery furnace particulate emissions, some mills have installed a secondary wet scrubber following the primary scrubber (direct-contact evaporator). Limited pilot plant studies and experience in some plants have shown that weak wash (weak caustic solutions) has removed hydrogen sulfide from the stack gases. In other instances, no hydrogen sulfide removal has been obtained in such a system. In general, the removal of hydrogen sulfide from flue gases containing 11 to 14 percent carbon dioxide with a caustic solution has not been developed.[30,31,151]

Clement and Elliott[45] have emphasized that the formation of malodorous gases in kraft mills takes place during incomplete oxidation in both the contact evaporator and recovery furnace. They recommend the elimination of the direct-contact evaporator by replacing it with a multiple-effect evaporator. This step--together with complete combustion in the upper part of the furnace by thorough mixing of additional air admitted through secondary and tertiary air ports--has resulted in reducing the hydrogen sulfide to less than 1 ppm and organic malodorous compounds to nondetectable concentrations. Clement and Elliott further point out that in 1968, 45 plants in Sweden and 3 in the United States were using such as arrangement.

Hochmuth[109] has reported that Combustion Engineering, Inc. has developed a heat exchanger to use the recovery furnace gases to preheat air for the direct-contact evaporation. Gases leaving the direct-contact evaporator are then incinerated. This method eliminates the contact evaporator as an odor source.

Another source of odorous emissions from kraft mills is provided by the noncondensible gases released for digesters and multiple-effect evaporators. These emissions have been minimized by various systems, generally based on collecting the noncondensible gases in a gas holder, then oxidizing or burning them at a constant flow rate. The various methods used are the following:

(1) Burning the gases in the recovery furnace or lime kiln.[250]

(2) Oxidizing the gases in a separate catalytic oxidizing furnace or a direct-flame incinerator.[151,245]

(3) Oxidizing the gases in an absorption tower with aqueous chlorine solutions, such as chlorine bleach water from the bleach plant, waste chlorine, hypochlorite, etc. Sometimes this is followed by passing them through

another absorption tower, where the absorbent is either a weak chlorine solution or a caustic solution.[134,250,296]

(4) Absorbing the gases with a caustic solution in a scrubber.[134]

Sableski[243] mentions that the gases can be collected in a floating roof tank rather than the Vaporsphere, thus avoiding the problem of diaphragm leakage.

In the lime kiln, odorous emissions may be substantially reduced through the use of wet scrubbers with an alkaline absorbent, efficient control of cumbustion, and proper washing of lime mud. Scrubbing smelt tank gaseous emissions with weak wash or green liquor in an absorption tower will reduce odorous emissions from this source.[250]

Around 1951, masking of odors by adding aromatic compounds to the digester, the black liquor, and the stack gases was tried in the United States. This strictly makeshift approach did not solve the basic pollution problem and is not used at the present time.[296]

### 4.4 Coke Ovens and Coal

In coke-oven plants, gases are often removed by passing the gases through iron-oxide-impregnated wood shavings.[10,145,266] This process is generally nonregenerative, although methods for regenerating the iron oxide have recently been developed.[161] Regenerative liquid absorption systems using such absorbents as ammonium carbonate, sodium thioarsenate, and sodium arsenate solutions have also been used.[89,145]

### 4.5 Diesel Engine Odors

The similarity between smoke- and odor-causing factors in diesel exhaust suggests that the same methods to control one will control the other to some extent. This is further indicated by Rounds and Pearsall[239] in their summary: "Several special approaches to exhaust gas odor reduction were tried, but no panacea was found. For the present, close attention should be given to factors such as improved engine and injector design, proper fuel and oil, good maintenance, and avoidance of overloading."

Some work is being done to develop exhaust converters to reduce diesel odor. However, numerous engineering problems remain to be solved. The sulfur content of fuel and the type of lubricating oil used appear to be more important with respect to odor and irritation than to smoke. Decreasing the scavenging air of two-stroke engines has improved fuel economy, decreased exhaust volume, and presumably decreased odor intensity.[252] Along the same lines, London[158] has suggested, "Possibly the light load stench can be reduced by intake air throttling so as to reduce the air-to-fuel ratio from 80 to 90 down to 50 to 60."

Odorants or masking agents offer a different approach to the diesel odor problem. In this connection, the Cleveland Transit System, General Motors Diesel Coach Division, Sindar Corporation, and Rhodia Company, Inc. conducted tests for approximately 1 year on the effects of masking agents. They concluded at the end of that time that:[158,252]

(1) The main combustion products have not been altered by the additives tested.

(2) Normal engine life is not affected.

(3) Additives can be completely soluble in the fuel and do not form deposits before or after combustion.

(4) There was little, if any, reduction of odor intensity or of eye, nose, or throat irritation.

(5) Odor quality was changed and improved.

The cost of the additive increased the price of diesel fuel by about 0.2 cent per gallon.

## 4.6 Meat Industry

### 4.6.1 Feedlots

Control of feedlot odors depends primarily on sanitation and housekeeping. If the pens are paved with either concrete or asphalt, daily cleaning and manure removal may be necessary. According to Moorman[193] and Faith,[78,260] it is important that there be adequate drainage so that manure will dry. If the manure can dry before putrefaction takes place, then manure need only be removed two or three times per year. One method of accelerating the drying process is to scarify the manure with a spring-tooth harrow to enhance evaporation.

The use of odor counteractants have proven to be more successful than the use of a masking agent. Moorman[193] points out that in some cases more complaints were received when masking agents were used than when the manure odor was untreated. Another common method of control is with potassium permanganate. The treatment consists of spraying a 1 percent solution of potassium permanganate (20 pounds per acre) in the corrals.

Removal of manure in commercial feedlots presents a problem because there is considerably more supply than demand for the raw material. Therefore, manure dehydrators have in many cases been installed adjacent to feedlots to package manure for shipment and sale. Storage and handling become important in relation to both the odor problem and the cost of operation. An odor control agent such as potassium permanganate is usually all that is necessary to prevent odor problems during storage. The application of counteractants prior to bagging can serve to deodorize the bagged material and plant exhaust.[193]

### 4.6.2 Livestock Slaughtering

As has been explained, odorous air contaminants are emitted from several points in a slaughtering operation. Installing control equipment at each source would be difficult if not impossible. Methods of odor control available include (1) rigid sanitation measures to prevent the decomposition of animal matter, and (2) complete enclosure of the operation to capture the effluent and exhaust it through a control device.[51]

When slaughtering is government-inspected, the operators are required to wash their kill rooms constantly, clean manure from stock pens, and dispose of all by-products as rapidly as possible. These measures normally hold plant odors to tolerable levels.[51]

When a slaughterhouse is located in a residential area, the odor reduction afforded by strict sanitation may not be sufficient. In these instances, full-plant air conditioning may be necessary. Filtration with activated carbon has been cited[51] as the only practical means of controlling the large volume of exhaust gases from a plant of this type. The latter method has not yet been employed at slaughterhouses in the United States. Nevertheless, activated-carbon filtration of the entire plant has been employed to control similar odors at animal matter by-product plants. With increasing urbanization, this method of control may conceivably be used in the near future.[51]

### 4.6.3 Inedible Rendering of Animal Matter

The principal devices used to control odorant emissions from rendering plants are afterburners and condensers, installed separately or in combination. Adsorbers and scrubbers are also used. Selection of the odor control equipment depends largely on the moisture content of the malodorous stream. Steam-laden streams can be controlled by condensation, while those from air driers and auxiliary processes require incineration, scrubbing, or adsorption.[51] Walsh[293] claims that combinations of condensers and incineration devices have been utilized to achieve odor removal efficiencies greater than 99.99 percent. He suggests that surface condensers are more desirable than contact condensers because the odor-laden water cannot be run through a cooling tower.

Mills et al.[180] have reported odor removal efficiencies from a dry rendering cooker. These data are tabulated in Table 43, Appendix B.

Exhaust gases from air drying processes must be incinerated, according to Walsh,[293] because they contain about 80 percent air and other noncondensible gases. The recommended incineration temperature is 1,200°F.

Carbon adsorbers are as efficient as afterburners.[51] Strauss[265] has reported that the use of activated charcoal adsorbers following a surface condenser-cooling tower arrangement has virtually eliminated odors from a rendering plant in Australia. The surface area of the carbon bed is large enough to give a linear velocity of 40 ft/min, and the usable life of the carbon is 6 months.

Scrubbing solutions of both sodium hypochlorite[197] and potassium permanganate[51] have been used to oxidize odorants from rendering plants. Mills et al.[180] claim that an afterburner is more efficient than a chlorinator. However, the chlorinator-scrubber has been successful in removing odors from fish meal driers[179] and a glue factory.[197] Posselt and Reidies[218] have reported odor reduction by oxidation with potassium permanganate. The results of their experiments are shown in Table 44, Appendix B.

Use of odor counteractants and masking agents have shown limited success in the local area of the rendering plant but are of little use in abating the odor pollution.[51,260]

### 4.7 Sewage

Santry[245] has reviewed the odor control methods for sanitary sewers and claims that control methods fall into these categories: physical control, chemical control, biological control, and a combination of these.

In sewage plants, the most comprehensive elimination of odors is accomplished by enclosing the process and venting the gases to an incinerator.[153] Odorous gases are piped from critical points in the plant and burned at temperatures of 1,100 to 1,500°F.[86] Afterburners are also employed to control odor emissions from sewage treatment plants.

Other methods of removing odors are absorption or chemical oxidation of the gas. The oxidation process is utilized in New York City and in Sarasota, Fla.[235] Ullrich and Ruff[286] reported on a catalytic oxidation unit that was used to control sewer odors in Austin, Tex.

In sewers, the production and release to the atmosphere of sewage gas can be minimized by maintaining sufficient velocities of sewage to avoid buildup, minimizing pressure lines, minimizing points of high turbulence, insuring adequate ventilation, injecting air to maintain aeration, cleaning sewers to remove slime and silt, using chemicals such as chlorine and ozone to suppress biological activity,[182] and adding specific biota to suppress the development of organisms producing hydrogen sulfide.[245] A method of preventing release of odorous gas to the atmosphere that has had some degree of success is trapping the gas in laterals, branches, and mains by use of specially designed junctions, followed by incineration.[245] A method utilized by the County Sanitation District of Los Angeles to control hydrogen sulfide is to add lime slurry periodically in relatively large quantities.[245]

## 5. ECONOMICS

Economically, the impact of odors is far-reaching. Because noxious and foul odors can ruin personal and community pride, interfere with human relations, discourage capital investment, lower socioeconomic status, and damage a community's reputation, the economics of a community may be closely related to any odor pollution problem. Both people and industry desire to locate in a desirable area in which to live, work, and play; the natural tendency is to avoid communities and localities with obvious odor problems. Tourists shun polluted areas. The resulting decline in market and rental property values, tax revenues, payrolls, and sales can be disastrous to a community.[126,166,263]

However, industries which cause odor pollution may be an economic advantage to a community, since they provide job opportunities both in the industry itself and in businesses which service the industry and its employees.

There are many socioeconomic aspects to odors which are difficult to assess. However, some incidents are easily evaluated. For example, a downtown theater in Washington D.C., was once evacuated because of some odor which penetrated the theater, requiring the manager to refund the price of admission. The exact source of the odor was not reported, but sewer gas was suspected.[302]

The cost of odor control by an industry is economically important. Often the cost is offset by economic benefits gained through the control methods or from recovery of waste products. For example, odorous compounds are often controlled by incineration, and the heat generated by incineration used to provide heat for some industrial process. Good examples are the heat from the recovery furnace in kraft pulp mills, heat recovered from incineration of odorous gases in rendering plants, and heat produced from sewage gas burners.

Typical costs of control equipment installed in Los Angeles County are listed in Table 45, Appendix B. Byrd and Phelps[36] have presented a method of arriving at what may be the most economical approach to odor control. They suggest determining the emission rate (odor units per minute) at each source of emission in a plant and the cost for its control. The cost per 1,000 units reduction can then be computed, thus allowing management to assess the costs of making improvements prior to expenditure of funds.

According to the American Petroleum Institute, as reported by Elkin,[71] odor control costs in the petroleum industry increased by a factor of eight in the 10-year period 1956 through 1966. This represented an increase of from 6 percent of total air pollution abatement expenditures by the industry in 1956 to 28 percent in 1966 (see Table 46 in Appendix B).

Kasparick[139] stated in 1965 that duPont had spent nearly $100,000 on odor control for a neoprene chemical plant, and furthermore, that the company had to abandon some promising projects that could have saved thousands of dollars annually because these projects would have contributed to an odor pollution. In the same report, this author states that the B.F. Goodrich Co. estimated that the annual fuel cost for incineration of odorant effluents from their rubber plant could be reduced from $26,600 to $10,650 by installing a recovery heat exchanger.[139]

Reed and Truitt[228] suggest that the cost of operating an auxiliary gas burner to control odors in a 100-unit apartment building will cost $490 per year for each unit and about 41 cents per month for each suite served.

The pulp and paper industry has spent about $75 million to date to control air pollution emissions. This figure includes $40 million spent over the last 4 years. In the next 4 years, the industry expects to spend $60 million. The cost includes the amounts spent for all phases of air pollution, including process changes in kraft mills.[85]

Because of the large volumes of gases exhausted from animal rendering plant driers, afterburner fuel requirements are a major consideration in odor pollution control. A drier emitting 3,000 scfm[a] requires about 4,800 scfh[b] of natural gas for 1,200°F incineration. Means of recovering the waste heat include using a steam generator and preheating the drier air.[51]

Strauss[265] examined the economics of three control systems for a rendering plant, as shown in Table 47, Appendix B. He concluded that the air-cooled unit (being a single unit) was cheaper to install than the surface condenser and cooling tower combinations which became less economical for operating periods greater than 3 years. The operating costs of the direct spray condenser eliminated it from further consideration in comparison with the other two units. The cost of scrubbing rendering plant gas with potassium permanganate is reported to be $8.40 per day on a

---

[a] scfm-standard cubic feet per minute.

[b] scfh-standard cubic feet per hour.

20,000 cfm scrubber using a 1 to 2 percent solution of potassium permanganate.[260]

Many cities in the United States may be faced with sewer-odor problems similar to those in Chicago (see Section 3.4.2). To eliminate the odors emanating from the manholes would be very expensive. The Chicago Sanitary District serves approximately 5,000,000 people and produces industrial wastes equivalent to wastes from 3,000,000 people. Their sewage systems, covering an area of 900 square miles, drain into five major treatment plants. To modernize even one of these--such as the Stickney treatment plant--to handle sewage in a nonoffensive manner would cost over $5,000,000.[229]

## 6. METHODS OF ANALYSIS

Methods of odor analysis may be divided into two groups: organoleptic, and chemical or instrumental. The organoleptic methods, which rely on detection with the human nose, are completely subjective, but other methods are available to convert the subjective measurements into some meaningful objective results. Chemical or instrumental methods for analyzing odorants--which are numerous--usually suffer from lack of sensitivity. Sensitive noses can detect odors in quantities impossible to identify and monitor with commercially available instrumentation or chemical methods.[164]

### 6.1 Sampling Methods

Samples may be collected in 250-ml Pyrex gas collecting tubes. The air sample is aspirated with a rubber squeeze bulb into the tube and isolated with stopcocks at both ends of the tube.[26,97]

### 6.2 Qualitative Methods

Only the nose can measure odor quality, and even then, results are strictly qualitative. The odor surveys that have been conducted are examples of qualitative odor analyses. In these surveys, high school students, firemen, and panelists have been asked to sniff ambient air or air samples and describe the odor quality, strength, and acceptability.[26,97]

## 6.3 Quantitative Methods

### 6.3.1 Organoleptic Methods

The most common method used is the vapor dilution technique. With this method, a sample is usually taken at the sampling station (in ambient air, a plant waste-gas stream, or any other desired sampling point) with a gas sampling tube. The sample is then returned to the laboratory, where it is diluted, usually by means of a syringe, and presented to a panel of observers for evaluation of the odor threshold dilution.[26,162,164,256]

A modification of this method is the syringe dilution technique. The sample is collected in a syringe and removed in part to another syringe for dilution to produce a test dilution for human appraisal. Sensitivity limits this method to use with nonambient odors. However, it has the advantage of being simple and easily portable. Benforado et al.[26] consider removal of the samples to the laboratory for analysis an advantage, but Gruber et al.[97] believe this to be a disadvantage.

The vapor dilution method may be a static method, a continuous method, or a volatilization technique. Some instruments that have been based on the vapor dilution method, using the human nose as the detector, are listed below:

(1) Static Method
Checkovich-Turner Osmometer[164]
Barail Osmometer[21]
Elsberg-Levy Olfactometer[74,75]
Fair-Wells Osmoscope[202]

(2) Continuous Method
Allison-Katz Odorimeter[83]
Zwaardemaker Olfactometer[312]
Procter and Gamble Osmo[102]
Scentometer[97]
Nader Odor Evaluation Apparatus[196]

(3) Volatilization Technique
Flask Dilution Method[135]
Enclosed Sniff-Blotter Technique[164]

Of these instruments, the scentometer requires special mention because it is portable, inexpensive, and requires only one man for its operation. However, this last advantage may become a disadvantage when it is desirable to have the opinion of an odor panel rather than a single person. The instrument has several ports which allow air to pass through activated charcoal to provide "clean" air for dilution with the odorous air sample. By opening and closing the ports, the operator can adjust the dilution threshold concentration. Moreover, he can breathe "clean" air to allow his nose to recover from olfactory fatigue, the main problem associated with sniffing.

Other methods, based on such properties as vapor adsorption, liquid dilution, and diffusion, are the following:

(1) The vapor adsorption and breakthrough method is based upon the time required for odor to "break through" an adsorber column of known volume. The Moncrieff Adsorption Unit is based on this technique.[187]

(2) The liquid dilution method uses an odorless solvent to dilute the odorous material, and the human appraisal is made on either the flask of diluent or on fractions of the diluent. The Elsberg-Levy Olfactometer[74,75] and Foster-Smith-Scofield Stimulator[83] use this technique.

(3) The rate of diffusion method requires the odorant to be placed on an adsorptive surface at the end of a diffuser column which encloses odorless, static air. Rates of diffusion may be measured by determining the time required by the odorant to diffuse through the full length of the tube (Ramsey Unit[223]) or the diffusion time may be detected as the odorant passes sniff ports along the length of the tube (Snell Laboratory Air Force Unit[90]).

Turk[285] has described a method for determining the intensity and character of diesel exhaust odors. In this method an odor panel is screened by giving each person a triangle test and intensity test. The triangle test consists of allowing each person to sniff five sets of three samples. Two of three samples are identical, while the third is different. He must detect which sample is different. The intensity test requires the person to rank in intensity a solution of odorant with a series of dilutions of the same odorant. Panelists selected are then asked to compare diesel exhaust gases with standards. In Turk's method, the standards were 32 liquids contained in polyethylene bottles. The head gas expelled by squeezing the bottles served as the reference odors. Overall exhaust odor intensity was rated on a 1 to 12 scale, and the qualities "burnt," "oily," "pungent," and "aldehyde/aromatic" were each rated on a 0 to 4 scale representing the following intensities: none, slight, moderate, strong, and extreme.

Duffee[65] reports that Battelle has developed a sniff kit for rendering plant odors. Methyl disulfide is presented to a human odor panel at five concentrations, ranging from 0.001 to 10 percent, for comparison with the rendering odors. He claims that the kit may be used by a single untrained observer to determine the effectiveness of odor control systems for rendering odorants or to compare odorant sources within or between plants.

### 6.3.2 Instrumental Methods

Gas chromatography has been exploited by several investigators[16,32,81,243] as a means of measuring odorants in the range of the odor threshold concentration of the mercaptans. Applebury and Schaer[16] have reported successful results. They used a 40-ml sample and a Porapak Q column (1/4" x 6') at 90°C. The detector was a coulometric cell with platinum electrodes similar to a design recommended by Adams et al.[3] The reported minimum detectable concentrations were the following:

| | |
|---|---|
| Hydrogen sulfide | 0.1 ppm, 150 μg/m³ |
| Methyl mercaptan | 0.5 ppm, 1,000 μg/m³ |
| Sulfur dioxide | 0.5 ppm, 650 μg/m³ |

Stevens et al.[261a] have developed a gas chromatography method which they claim can be used to determine the concentration of sulfur dioxide and other odorous gases produced in kraft paper mills. Polyphenyl ether was coated (4 percent) on 30-40 mesh teflon powder containers and packed in 24 feet of teflon tubing. A small amount (0.05 percent) of phosphoric acid was also added. It was found that sulfur dioxide, hydrogen sulfide, methyl mercaptan, and carbon disulfide could be separated by this column with very little loss. A flame photometric detector was used to measure concentrations down to 0.01 ppm.

## 7. SUMMARY AND CONCLUSIONS

Offensive odors in the air are a major air pollution problem in some areas. These malodors cause many complaints, provoking emotional disturbances, mental depression, and irritability. In some instances health effects such as nausea, vomiting, headache, loss of sleep, loss of appetite, and impaired breathing are induced. Contact with odorants may cause varying degrees of reactions in allergic individuals, particularly children.

Sociologically, odor pollution can interfere with human relations in many ways. It can damage personal and community pride, discourage capital investment, and lower the socioeconomic status of both the individual and the community. Some State, county, and city governments have enacted laws that prohibit the emission of air pollutants which unreasonably interfere with the enjoyment of life and property. However, no odor standard has been established.

No information has been found on the effects of odor air pollution on animals. Odors _per se_ have no effect on plants or materials. However, some odorants such as hydrogen sulfide and sulfur dioxide may affect animals, plants, and materials.

The sources of odors are numerous and include pulp and paper mills, animal rendering plants, sewers and sewage treatment plants, garbage dumps and incinerators, chemical plants, petroleum refineries, metallurgical plants, and internal combustion engines, particularly diesel and aircraft engines. The most offensive odors come from plants or processes which produce low molecular weight sulfur and nitrogen compounds, such as ethyl- and methyl-mercaptans, hydrogen sulfide, ammonia, and dimethylamine. Environmental air concentrations of obnoxious odorants frequently exceed the odor threshold concentration in some local areas, and the odor has on occasions been recognized 20 miles from the source.

The most generally accepted method of abatement of odors is incineration at the source. However, improper incineration may in itself be a source. Other abatement methods include adsorption, absorption, particulate removal, source elimination, process changes, chemical control, containment, odor masking, odor counteraction, biological control, and dilution.

Economically, noxious odors may stifle the development and growth of a community. Both people and industry desire to locate in a place where it is pleasant to work, live, and play. Tourists shun polluted areas, and rental and real estate property values may decrease. The control of odor pollution is often very costly to an industry, depending on the odor problem and the type of industry. This cost may be reduced by economic benefits derived from recovered heat or waste products. About $75 million have been spent for air pollution control in the kraft paper industry alone.

Both laboratory and field methods have been developed for measurement of odors at the source and in the ambient air. The human nose is the only valid odor detector, and all methods rely on the judgment of one or more people who make up the odor panel. Only gas chromatography has been developed to measure hydrogen sulfide, methyl mercaptan, and sulfur dioxide at concentrations near the odor threshold.

Based on the material presented in this report, further studies are suggested in the following areas:

(1) Development of odor emission recommendations, based on the effect of meteorological conditions on rate of odor emission (odor units per minute).

(2) Measurement of the odor concentrations at various distances from sources.

(3) Study of the pervasive character of the most offensive odorants.

(4) Development of methods for detecting the most offensive odorants so that these odorants may be monitored below the odor threshold.

REFERENCES

1. Absorption of Odorous Sulfur Compounds in Chlorine and Caustic Solutions, National Council for Stream Improvement, New York City, Atmospheric Pollution Technical Bulletin No. 23 (March 1965).

2. Adams, D. F., R. K. Koppe, and W. N. Tuttle, Analysis of Kraft-Mill, Sulfur-Containing Gases with GLC Ionization Detectors, *J. Air Pollution Control Assoc*. *15*(1):31 (1965).

3. Adams, D. F., *et al*., Improved Sulfur Reacting Microcoulometric Cell for Gas Chromatography, *Anal. Chem*. *38*(8): 1094 (1966).

4. *Air Pollution Abatement Manual*, Manufacturing Chemists Assoc., Inc. (1955)

5. Air Pollution in the El Paso, Texas, Area, El Paso City-County Health Unit, 1959.

6. Air Pollution: The "Feds" Move to Abate Idaho Pulp Mill Stench, *Science* *157*:1018 (1967).

7. The Air Pollution Situation in Terre Haute, Indiana, with Special Reference to the Hydrogen Sulfide Incident of May-June 1964, U.S. Public Health Service (1964).

8. Air Quality in Clark County, Wash., Washington State Department of Health, Seattle, Wash. (May 1965).

9. Air Quality Data from the National Air Sampling Networks and Contributing State and Local Networks 1964-1965, U.S. Public Health Service, Cincinnati, Ohio (1966).

10. Altybaev, M., and V. V. Streltsov, Removal of Sulfur Compound from Gaseous Fuels, *Coke Chem. (USSR)* *8* (1966).

11. Amoore, J. E., *Perfumery Essent. Oil Record* *43*:321 (1952); *Chem. Abstr*. *47*:2427 (1953).

12. Amoore, J. E., The Stereochemical Theory of Olfaction, *Proc. Sci. Sect. Toilet Goods Assoc*., Special Suppl. to Vol. 37 (i) (1962).

13. Amoore, J. E., *Nature* *198*:271 (1963).

14. Amoore, J. E., *Ann. N.Y. Acad. Sci*. *116*:457 (1964).

15. Amoore, J. E., J. W. Johnston, Jr., and M. Rubin, *Sci. Am*. *210*(2):42 (1964).

16. Applebury, T. E., and M. J. Schaer, Analysis of Kraft Pulp Mill Gases by Process Gas Chromatography, Dept. of Chem. Eng., Montana State Univ., Bozeman, Mont. (1968)

17. Atmospheric Emissions from Oil Refineries, U.S. Public Health Serv. Publ. 763 (1963).

18. Backman, E. L., Note sur la puissance des odeours et leur solubilite dans l'eau et dans l'huile, J. Physiol. Path. Gen. 17:1 (1917).

19. Baikov, B. K., Basic Experimental Data for the Determination of Maximal Permissible Concentrations of Carbon Disulfide and Hydrogen Sulfide Simultaneously Present in the Air; Translated by B. S. Levine, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 12:47 (1963).

20. Baradi, A. F., and G. H. Bourne, Science 113:660 (1951).

21. Barail, L. C., Odor Measurement, Soap and Sanitary Chem. 25(6):133 (1949).

22. Barnebey, H. L., Activated Charcoal for Air Purification, Trans. Am. Soc. Heating Air-Conditioning Eng. 64:481 (1958).

23. Beck, L. H., and W. R. Miles, Some Theoretical and Experimental Relationships Between Infrared Absorption and Olfaction, Science 106:511 (1947).

24. Beets, M. G. J., Molecular Structure and Organoleptic Quality, Soc. Chem. Ind. (London) Monograph No. 1 (1957).

25. Benforado, D. M., and G. Cooper, The Application of Direct-Flame Incineration as an Odor Control Process in Kraft Pulp Mills. Presented at the 22nd Engineering Conf., Process Systems and Controls, Water and Air Pollution, Technical Association of the Pulp and Paper Industry, Atlanta, Ga. (Sept. 19-22, 1967).

26. Benforado, D. M., W. J. Rotella, and D. L. Horton, Development of an Odor Panel for Evaluation of Odor Control Equipment, J. Air Pollution Control Assoc. 19(2): 101 (1969).

27. Berger, L. B., and R. T. Artz, Performance of a Diesel Mine Locomotive, Report of Investigation 4287, U.S. Bureau of Mines (May, 1948).

28. Biederman, J. B., Sensitivity to Flowers, Laryngoscope 47:1649 (1941).

29. Blinova, E. A., Industrial Standards for Substances Emitting Strong Odors, Hyg. Sanit. (Gigiena i Sanit) 30(1):18 (1965).

30. Blosser, R. O., and H. B. H. Cooper, Jr., Secondary Scrubbing of Kraft Recovery Stack Gas, Presented at 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minn. Paper No. 68-129 (June 23-27, 1968).

31. Blosser, R. O., and H. B. H. Cooper, Jr., Trends in Atmospheric Particulate Matter Reduction in the Kraft Industry, Tappi 51(5):73A (1968).

32. Brooman, D. L., and E. Edgerley, Jr., Concentration and Recovery of Atmospheric Odor Pollutants Using Activated Carbon, J. Air Pollution Control Assoc. 16:25 (1966).

33. Brown, E. A., Persistent Cough and Bronchospasm Due to Exposure to Fumes of Range Oil, Ann. Allergy 7:756 (1949).

34. Brown, E. A., and N. J. Colombo, The Asthmogenic Effect of Odors, Smells and Fumes, Ann. Allergy 12:14 (1954).

35. Buell, G. C., and P. K. Mueller, Toxicity of Ozone, AIHL-Rept. No. 18, State of Calif. Dept. of Public Health, Air and Ind. Hyg. Lab., Berkeley, Calif. (Sept. 1965).

36. Byrd, J. F., and A. H. Phelps, Jr., in Air Pollution, vol. II, 2nd ed., A. C. Stern, Ed. (New York: Academic Press, p. 325, 1968).

37. Byrd, J. F., et al., Solving a Major Odor Problem in a Chemical Process, J. Air Pollution Control Assoc. 14(2):509 (1964).

38. California Standards for Ambient Air Quality and Motor Vehicle Exhaust, Suppl. No. 2, Additional Ambient Air Quality Standards. State of California, Dept. of Public Health (1962).

39. California Standards for Ambient Air Quality and for Motor Vehicle Emissions, State of California, Dept. of Public Health, Bureau of Air Sanitation (March 1967).

40. Cajort, A., Letters of the International Corresp. Soc. of Allergies, Series 17 (1953).

41. Carl, C. E., and G. L. Christensen, Appraisal of Air Pollution in South Dakota, South Dakota State Dept. of Health Div. of Sanitary Engineering and U.S. Public Health Serv. (Aug. 1962).

42. Carver, T. O., et al., An Approach to a Solution of an Interstate Air Pollution Problem, Presented at the Annual Meeting of the Air Pollution Control Association, Houston, Tex. (June 1964).

43. Cederlof, R., et al., Studies of Annoyance Connected with Offensive Smell from a Sulphate Cellulose Factory, Nord. Hyg. Tidskr. XLV:39 (1964).

44. Chass, R. L., The Status of Engineering Knowledge for the Control of Air Pollution, Proc. of Natl. Conf. on Air Pollution, Washington, D.C. (Dec. 10-12, 1962); U.S. Public Health Serv. Publ. 1022 (1963).

45. Clement, J. L.,and J. S. Elliott, Kraft Recovery Boiler Design for Odor Control, Presented at the 4th Paper Industry Air & Stream Improvement Conference, Halifax, Nova Scotia (Sept. 17, 1968).

46. Coca, A. F., Asthma and Hay Fever (Springfield, Ill.: Charles C Thomas, 1931).

47. Collins, R. P., and H. D. Gains, Appl. Microbiol. 12:335 (1964).

48. Control and Disposal of Cotton-Ginning Wastes, A Symposium at Dallas, Texas, May 3-4, 1966, U.S. Public Health Service, Cincinnati, Ohio (1967).

49. Control Techniques for Particulate Air Pollutants, National Air Pollution Control Administration Publication AP-51 (Jan. 1969).

50. Cosentine, M. V., Control of Atmospheric Odors from Fermentation Processes, Air Pollution Control Assoc. News 4 (Dec. 1956).

51. Danielson, J. A. (Ed.), Air Pollution Engineering Manual, Air Pollution Control District County of Los Angeles. U.S. Public Health Service, Bureau of Disease Prevention, Environmental Control, National Center for Air Pollution Control, Cincinnati, Ohio (1967).

52. Davies, J. T., A Model System for the Olfactory Membrane Nature 174:693 (1954).

53. Deadly Gases in Piggeries, German Res. Serv. 5(5):9 (1966).

54. Deamer, W. C. in The Allergic Child, F. Speer (Ed.) (New York: Hoeber-Harper, 1963).

55. DeBesche, A., On Asthma Bronchiale in Man Provoked by Various Kinds of Animals, Acta Med. Scand. 92:209 (1937)

56. Decker, H., Praktikum der Allergischen Krankheiten (Montana, 1930).

57. Delange, R., Residual Valency and Odor, Bull. Soc. Chim. Belges 31:589 (1922).

58. Denmead, C. F., Air Pollution by Hydrogen Sulphide from a Shallow Polluted Tidal Inlet, Auckland, New Zealand, Clean Air Conference, First Technical Session. Proc. Clean Air Conf. Univ. New South Wales 1:20 (1962).

59. Derbes, V. J., and H. T. Englehardt, Urticaria Due to Inhalant Substances, Southern Med. J. 37:729 (1944).

60. Derbes, V. J., and J. D. Krofchuk, Osmulogenic Urticaria, A.M.A. Arch. Dermatol. 76:102 (1957).

61. Diesel Exhaust Composition and Odor: Progress Report for Year 1965, Scott Research Laboratories, Inc. (Oct. 1966).

62. A Digest of State Air Pollution Laws, 1967 ed., U.S. Public Health Serv. Publ. 711 (1967).

63. Dixon, J. P., The State of Our Atmosphere, Proc. Third National Conference on Air Pollution, Washington, D.C. (Dec. 12-14, 1966).

64. Dixon, J. P., and J. P. Lodge, Air Conservation Report Reflects National Concern, Science 148 (1965).

65. Duffee, R. A., Appraisal of Odor-Measurement Techniques, J. Air Pollution Control Assoc. 18(7):472 (1968).

66. Duke, W. W., Allergy: Asthma, Hay Fever, Urticaria and Allied Manifestations of Reaction (St. Louis: Mosby, 1927).

67. Durrans, T. H., Residual-Affinity Theory of Odors, Perfumery Essent. Oil Record 11:391 (1920).

68. Dyson, G. M., Perfumery Essent. Oil Record 19:456 (1928); Chem. Abstr. 23:853 (1929).

69. Dyson, G. M., Perfumery Essent. Oil Record 28:13 (1937).

70. Dyson, G. M., Scientific Basis of Odour, Chem. Ind. 57:647 (1938).

71. Elkin, H. F., "Petroleum Refinery Emissions," in Air Pollution, vol. III, 2nd ed., A. C. Stern, Ed. (New York: Academic Press, 1968).

72. Elliott, M. A., and R. F. Davis, Composition of Diesel Exhaust Gas, Presented at Society of Automotive Engineers National Diesel Engine Meeting, St. Louis, Mo. (Nov. 1949).

73. Elliott, M. A., et al., The Composition of Exhaust Gases from Diesel Gasoline and Propane Powered Motor Coaches, J. Air Pollution Control Assoc. 5(2) (Aug. 1955).

74. Elsberg, C. A., and I. Levy, The Sense of Smell, I. A New and Simple Method of Quantitative Olfactometry, Bull. Neurol. Inst. 4:5 (1935).

75. Elsberg, C. A., I. Levy, and E. D. Brewer, A New Method for Testing the Sense of Smell, Science 83:211 (1936).

76. Epstein, S., Letter of the International Corresp. Soc. of Allergists, Series 17 (1953).

77. Fabre, J. H., Social Life in the Insect World (London: Underwood, 1927).

78. Faith, W. L., Odor Control in Cattle Feed Yards, J. Air Pollution Control Assoc. 14(11):459 (1964).

79. Feinberg, S. M., Living with Your Allergy (Philadelphia: Lippincott, 1958).

80. Feinberg, S. M., and R. L. Aries, Asthma from Food Odors, J. Am. Med. Assoc. 98:2280 (1932).

81. Feldstein, M., S. Balestrieri, and D. A. Levaggi, Studies on the Gas Chromatographic Determination of Mercaptans, J. Air Pollution Control Assoc. 15(5):215 (1965).

82. Fitton, A., "Air Pollution from Road Transport: Part I," in Proc. Mech. Eng. Clean Air Conf., London (1957).

83. Foster, D., L. A. Smith, and E. H. Scofield, A New Dirhinic Olfactory Stimulator, Am. J. Psychol. 60:272 (1947).

84. Fowler, P. B. S., Printer's Asthma, Lancet 2:755 (1952).

85. Frost and Sullivan, Inc., CAMP Reports on Air Pollution, New York (1969).

86. Fume Incineration Effective for Odor Pollution Control, Ind. Heating 33(7):1266 (1966).

87. Fyn-Djui, D., Basic Data for the Determination of Limit of Allowable Concentration of Hydrogen Sulfide in Atmospheric Air, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 5:66 (1961).

88. Gamble, E. A. M., Am. J. Psychol. 10:82 (1898).

89. Gang, S. N., Coke Gas Purification from Hydrogen Sulfide in High Speed Rotary Absorbers, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 4 (Aug. 1960).

90. Gee, A. H., Organoleptic Appraisal of Three Component Mixtures, American Society for Testing Materials Reprint 105b (1954).

91. Gex, V. E., and J. P. Snyder, New Device Wider Concept Helps to Measure Odors Quantitatively, Chem. Eng. 59(12): 200 (1952).

92. Glaser, J., Allergy in Childhood, (Springfield, Ill.: Charles C Thomas 1956).

93. Goldbeck, R. A., J. H. Kaeding, and W. E. Feroglia, Odor Coding for Malfunction Detection and Diagnosis, Philco Corp., Palo Alto, Calif. (Aug. 1966).

94. Goodale, I. L., The Present Status of Immunization in Hay Fever, Boston Med. Surg. J. 179:293 (1918).

95. Grekel, H., J. W. Palm, and J. W. Kilmer, Why Recover Sulfur from $H_2S$? Oil Gas J. 66(44) (1968).

96. Gruber, C. W., Odor Pollution from the Official's Viewpoint, Presented at the 57th Annual Meeting, American Soc. for Testing Materials, Chicago, Ill. (1954).

97. Gruber, C. W., G. A. Jutze, and N. A. Huey, Odor Determination Techniques for Air Pollution Control, J. Air Pollution Control Assoc. 10(4): 327 (1960).

98. Grunder, L. J., West Coast Diesel Odor Control - A Progress Report, Presented at the Meeting of Canadian Transit Association (March 1960).

99. Hainer, R. M., Theory presented at New York Basic Odor Conference (1953).

100. Harkavy, J., Skin Hypersensitiveness to Extract of Tobacco Leaf, Tobacco Pollen, Tobacco Seed, and to Other Allergens in 200 Normal Smokers, J. Allergy 6:56 (1934).

101. Harstad, A. E., Control of Odors from Feather Processing, J. Air Pollution Control Assoc. (March 1956).

102. Heller, H., A Critical Discussion of Teudt's Theory, Am. Perfumer 14:365 (1920).

103. Heller, A. N., Methods of Evaluating Socioeconomic Effects of Air Pollution, U. S. Public Health Service, Cincinnati, Ohio (July 12, 1966).

104. Hendrickson, E. R., and C. I. Harding, Black Liquor Oxidation as a Method for Reducing Air Pollution from Sulfate Pulping, J. Air Pollution Control Assoc. 14(12):487 (1964).

105. Henning, H., Der Geruch (Leipzig, 1916).

106. Henson, G. E., Garlic: Occupational Factor in Etiology of Bronchial Asthma, J. Florida M.D. 27:86 (1940).

107. Heyninx, A., Essai d'olfactigue physiologique, Thesis, Brussels (1919).

108. Hilleboe, H. E., A Review of Air Pollution in New York State, New York State Air Pollution Control Board (July 1958).

109. Hochmuth, F. W., Odor Control System for Chemical Recovery Units, Paper Trade J. 150 (Sept. 1968).

110. Holland, W. C., R. L. Klein, and A. H. Briggs, Chapter 13 in Introduction to Molecular Pharmacology (New York: Macmillan, 1964).

111. Holtz, J. C., et al., Diesel Engines Underground, IV. Effect on Composition of Exhaust Gas of Variables Influencing Fuel Injection, U. S. Bureau of Mines Report Investigation 3700 (April 1943).

112. Horesh, A. J., Allergy to Food Odors. Its Relation to the Management of Infantile Eczema, J. Allergy 14:331 (1943).

113. Horesh, A. J., Allergy to Odor of White Potato (Irish Potato), J. Allergy 15:117 (1944).

114. Horesh, A. J., Allergy Due to Food Odors, Pediatrics 6:654 (1950).

115. Horesh, A. J., The Role of Odors and Vapors in Allergic Disease, J. Asthma Res. 4(2):125 (1966).

116. Horstman, S. W., R. F. Wromble, and A. N. Heller, Identification of Community Odor Problems by Use of an Observer Corps, J. Air Pollution Control Assoc. 15(6):261 (1965).

117. Huey, N. A., Ambient Odor Evaluation, U. S. Public Health Service, National Center for Air Pollution Control, Cincinnati, Ohio (June 1968).

118. Huey, N. A., et al., Objective Odor Pollution Control Investigations, J. Air Pollution Control Assoc. 10(6): 441 (1960).

119. Hughes, K. J., and R. W. Hurn, A Preliminary Survey of Hydrocarbon Derived Oxygenated Material in Automobile Exhaust Gases, J. Air Pollution Control Assoc. 10(5) (Oct. 1960).

120. Hull, C. D., et. al., Nature 205:627 (1965).

121. Hurn, R. W., et al., The Potpourri That is Exhaust Gas Presented at the 27th Mid-Year Meeting of the American Petroleum Institute's Division of Refining, San Francisco, Calif. (May 1962).

122. Ilgenfritz, E. M., J. F. Shively, and M. E. Krienke, Surveying Air Quality at Dow Chemical Company, Air Eng. 7(10):20 (1965).

123. In Quest of Clean Air for Berlin, New Hampshire, Technical Report A62-9, U. S. Dept. of Health, Education, and Welfare, Cincinnati, Ohio (1962).

124. Industrial Air Pollution, Factory, 123(10):90 (1965).

125. International Critical Tables of Numerical Data, Physics, Chemistry and Technology. Vol. I, National Research Council of the U.S.A. (New York: McGraw-Hill, 1926).

126. Interstate Air Pollution in the Selbyville, Delaware - Bishop, Maryland Area. Preprint, U. S. Public Health Service, Div. of Air Pollution, Washington, D. C. (Nov. 1965).

127. Itskovics, A. A., The Stimulability of the Olfactory Analyser in the Hygienic Evaluation of Atmospheric Air Pollution, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 3:106 (1960).

128. Jaffe, L. S., The Biological Effects of Ozone on Man and Animals, Am. Ind. Hyg. Assoc. J. 28:267 (1967).

129. Jaffe, L. S., The Biological Effects of Photochemical Air Pollutants on Man and Animals, Am. J. Public Health 57(8): 1269 (1967).

130. Jamieson, H. C., Asthma Due to Odor of Urine, Feces and Sweat, Ann. Allergy 5:234 (1947).

131. Jenkins, H. N., and T. O. Harris, Interstate Air Pollution Study, Phase II. Project Report. IV. Odors - Results of Surveys, U. S. Public Health Service, Div. of Air Pollution, Cincinnati, Ohio (June 1966).

132. Jenkins, D., L. L. Medsker, and J. F. Thomas, Odorous Compounds in Natural Waters. Some Sulfur Compounds Associated with Blue-Green Algae, Environ. Sci. Technol. 1(9):731 (1967).

133. Jensen, D. A., Sources and Kinds of Contaminants from Motor Vehicles, Informative Report No. 4, J. Air Pollution Control Assoc. 14(8):17 (1964).

134. Jenson, G. A., D. F. Adams, and H. Stern, Absorption of Hydrogen Sulfide and Methyl Mercaptan from Dilute Gas Mixtures, J. Air Pollution Control Assoc. 16(5):248 (1966).

135. Jerome, E. A., Olfactory Thresholds Measured in Terms of Stimulus Pressure and Volume, Arch. Psychol. 39(274):5 (1942).

136. Jonsson, E., Annoyance Reactions to External Environmental Factors in Different Sociological Groups, Acta Sociologica (Copenhagen) 7(4):229 (1964).

137. Kaiser, E. R., in Air Pollution, vol. I., A. C. Stern, Ed. (New York: Academic Press, p. 250, 1962).

138. Kaiser, E. R., *et al.*, Performance of Flue-Fed Incinerators, J. Air Pollution Control Assoc. 9(2):85 (1959).

139. Kasparick, M. F., Odor Control for a Chemical Plant, Air Eng. (Jan. 1965).

140. Katz, S. H., and V. C. Allison, U. S. Bureau of Mines Tech. Paper 267 (1920).

141. Kenline, P. A., and J. M. Hales, Air Pollution and the Kraft Pulping Industry. An Annotated Bibliography, U. S. Public Health Service, Div. of Air Pollution (Nov. 1963).

142. Keogy, D. M., and J. J. Schueneman, Air Pollution in the Birmingham, Alabama Area, Technical Report A58-8, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio (1958).

143. Kerka, W. F., and E. R. Kaiser, An Evaluation of Environmental Odors, J. Air Pollution Control Assoc. 7(4) (Feb. 1958).

144. Kinosian, J. R., J. A. Maga, and J. R. Goldsmith, The Diesel Vehicle and Its Role in Air Pollution - A Report to the California Legislature, California Dept. of Public Health, Bureau of Sanitation (Dec. 1962).

145. Kirk-Othmer, Encyclopedia of Chemical Technology, 1st ed. (New York: Interscience, 1954).

146. Krasovitskaya, M. L., *et al.*, Atmospheric Pollution by Petroleum Refineries and Petrochemical Plants, Ufa Inst. Hyg. Occupational Health, UDC 614.72:665.5 (1964).

147. Kreichelt, T. E., Air Pollution Aspects of Tepee Burners Used for Disposal of Municipal Refuse, U. S. Public Health Serv. 999-AP-28 (1966).

148. Kreichelt, T. E., D. A. Kemnitz, and S. T. Cuffe, Atmospheric Emissions from the Manufacture of Portland Cement, U. S. Public Health Service, Cincinnati, Ohio (1967).

149. Krisch, W., quoted in Can. Chem. Proc. Ind. 23:115 (1939).

150. Kropp, E. P., and R. N. Simonsen, Scrubbing Devices for Air Pollution Control, Paint Oil Chem. Rev. 115(14):11 (1952).

151. Landry, J. E., and D. H. Longwell, Advances in Air Pollution Control in the Pulp and Paper Industry, Tappi 48(6): 66A (1965).

152. Larsen, R. I., *et al.*, Bases and Types of Air Quality Criteria, An Informative Report by Task Group 2 of Air Pollution Control Association Committee, TR-5 (1964).

153. Ledbetter, J. O., Air Pollution from Wastewater Treatment, Water-Sewage Works 113(2):43 (1966).

154. Leonardos, G., D. Kendall, and N. Barnard, Odor Threshold Determinations of 53 Odorant Chemicals, J. Air Pollution Control Assoc. 19(2):91 (1969).

155. Linnell, R. H., and W. E. Scott, Diesel Exhaust Analysis Techniques and Preliminary Results. Presented at U. S. Public Health Service and California Dept. of Public Health Air Pollution Research Conference, Los Angeles, Calif. (Dec. 5, 1961).

156. Linnell, R. H., and W. E. Scott, Diesel Exhaust Composition and Odor Studies, J. Air Pollution Control Assoc. 12(11):510 (1962).

157. Linsky, B., Report to Detroit Common Council on Emission of Odor, Smoke, Gas, etc. from Diesel-Engined Coaches (June 1955).

158. London, A. L., The Application of Research to Motor Vehicle Pollution Control - Can We Avoid Afterburners? Presented at the U. S. Public Health Service and California Dept. of Public Health Air Pollution Research Conference, Los Angeles, Calif. (Dec. 5, 1962).

159. Lozano, E. R., W. W. Melvin, and S. Hocheeser, Air Pollution Emissions from Jet Engines. Presented at the 60th Annual Meeting, Air Pollution Control Association, Cleveland, Ohio (June 1967).

160. Mackenzie, M., Hay Fever: Its Etiology and Treatment with an Appendix on Rosecold, London (1881).

161. Maddox, R. N., and M. D. Burns, Solids Processing for Gas Sweetening, Oil Gas J. 66(25) (June 1968).

162. Manual on Sensory Testing Methods, American Society for Testing Materials Special Tech. Publ. No. 434 (May 1968).

163. Marchand, L., Chemical Constitution of Odors, Deut. Parf. Ztg. 1:223 (1915).

164. Matheson, J. F., Olfactometry: Its Techniques and Apparatus, J. Air Pollution Control Assoc. 5(3):167 (1955).

165. Matsak, V. G., The Purification of Air Pollution by Vapors and Gases from the Central Sanitary and Hygienic Laboratory in Moscow, Gigiena i Sanit. 8 (1950).

166. Matsushita, H., et al., Determination of Threshold Values for Olfactory Perception of Primary Odour Substances, Ind. Health 5:221 (1967).

167. May, J., Odor Thresholds of Solvents for Assessment of Solvent Odors in the Air, Staub 26(9):34 (1966).

168. McCaldin, R. O., and P. A. Kenline, Air Pollution in Connecticut, U. S. Public Health Service, Cincinnati, Ohio (1957).

169. McCartney, W., Olfaction and Odours (Berlin: Springer, 1968).

170. McCord, C. P., and W. N. Witheridge, Odors: Physiology and Control (New York: McGraw-Hill, 1949).

171. McHard, J. D., and R. F. Wromble, O.K. Air for the O.K. State - a Report on the Appraisal of Air Pollution in Oklahoma, Oklahoma State Dept. of Health, Oklahoma City, Okla. (Jan. 1965).

172. Medalia, N. Z., Community Perception of Air Quality: An Opinion Survey in Clarkston, Washington, U. S. Public Health Service, Cincinnati, Ohio (1965).

173. Medsker, L. L., D. Jenkins, and J. F. Thomas, An Earthy-Smelling Compound Associated with Blue-Green Algae and Actinomycetes, Environ. Sci. & Technol. 2(6):461 (1968).

174. Melekhina, V. P., Maximum Permissible Concentration of a Formaldehyde in Atmospheric Air, Gigiena i Sanit. 23:10 (1958).

175. Mellor, J. F., A Multipurpose Flare Stack for Control of Chemical Process Wastes, J. Air Pollution Control Assoc. 10(6) (1960).

176. Mel'ster, F. G., et al., Reduction of Atmospheric Pollution in Tashkert, Tashkert Sanitary Epidemiological Center, Hyg. Sanitation 30(10-12):(1956).

177. Mencher, S. K., Change Your Process to Alleviate Your Pollution Problem, Petro/Chem Engr.39(5):214 (1967).

178. Miles, W. R., and L. H. Beck, Science 106:512 (1947).

179. Mills, J. L., J. A. Danielson, and L. K. Smith, Control of Odors from Inedible Rendering and Fish Meal Reduction in Los Angeles County. Presented at the 60th Annual Meeting of the Air Pollution Control Association, Cleveland, Ohio (June 1967).

180. Mills, J. L., et al., Quantitative Odor Measurement, J. Air Pollution Control Assoc. 13:467 (1963).

181. Missenden, J., Intensity and Quality of Odors, Perfumery Essent. Oil Record 17:62 (1926).

182. Mohanrao, G. J., C. A. Sastry, and W. F. Garber, Hydrogen Sulphide in Concrete Sewers and Digester, J. Inst. of Eng. (India) 46(6):90 (1966).

183. Molos, J. E., Control of Odors from a Continuous Soap Making Process, J. Air Pollution Control Assoc. 11(1):9 (1961).

184. Moncrieff, R. W., The Chemical Senses, 1st ed. (London: Leonard Hill, 1944).

185. Moncrieff, R. W., The Chemical Senses, 2nd ed. (London: Leonard Hill, 1951).

186. Moncrieff, R. W., Am. Perfumer Cosmet. 78(12):37 (1953); in Chem. Abstr. 60:6695 (1964).

187. Moncrieff, R. W., The Characterization of Odors, J. Physiol. 125:453 (1954).

188. Moncrieff, R. W., J. Appl. Physiol. 16:742 (1961).

189. Moncrieff, R. W., Drug Cosmetic Ind. 91:705 (1962).

190. Moncrieff, R. W., The Chemical Senses, 3rd ed. (London: Leonard Hill, 1967).

191. Moncrieff, R. W., Odor Preferences (London: Leonard Hill, 1968).

192. Monganelli, R. M., and C. J. Gregory, The Effect of Hydrogen Sulfide on Various Surfaces, Atmospheric Pollution Technical Bulletin No. 25, National Council for Stream Improvement, Inc., New York (1965).

193. Moorman, R., Jr., Controlling Odors from Cattle Feed Lots and Manure Dehydration Operations. Presented at the Air Pollution Control Association Meeting (June 21-25, 1964).

194. Muller, A., Dipolar Theory of Olfaction, Perfumery Essent. Oil Record 27:202 (1936).

195. Nader, J. S., Current Techniques of Odor Measurement, Chemical Toxicological Conference, A.M.A. Arch. Ind. Health 17(5): (1958).

196. Nader, J. S., An Odor Evaluation Apparatus for Field and Laboratory Use. Presented at the 1957 Annual Meeting of the American Industrial Hygiene Association, St. Louis, Mo.

197. NaOCL Solves Odor Problem, Processes & Technology, p. 164. (1968)

198. National Goals in Air Pollution Research, Surgeon General's Ad Hoc Task Group on Air Pollution (Aug. 1960).

199. Niccolini, P., Detection of Odors, Boll. Soc. Ital. Biol. Sper. 8:424 (1933).

200. Nicol, H., The Perception of Odour, Perfumery Essent. Oil Record 17:176 (1926).

201. Nolan, M., A Survey of Air Pollution in Communities Around the John F. Kennedy International Airport, U. S. Public Health Service, Cincinnati, Ohio (June 1966).

202. Odor Determinations on a Numerical Basis...The Fair-Wells Osmoscopes, Bull. No. 524, Eimer & Amend, New York, N.Y.

203. Ogle, W., Med.-Chir. Trans. 53:263 (1870).

204. Oil Gas J. 67(4) (Jan. 1969).

205. Oil Gas J. 67(9) (Jan. 1969).

206. Oliver, E. A., Discussion to Templeton, J. Am. Med. Assoc. 127:910 (1945).

207. Owens, V. P., Considerations for Future Recovery Units in Mexican and Latin American Alkaline Pulping Mills, Combustion pp. 38-44 (Nov. 1966).

208. Owens, V. P., Trends in Odor Abatement from Kraft Mill Recovery Units, Paper Trade J. 152(33):52 (1968).

209. The Oxides of Nitrogen in Air Pollution, State of California, Dept. of Public Health, Bureau of Air Sanitation, Berkeley, Calif. (Jan. 1966).

210. Partee, F., Air Pollution in the Coffee Roasting Industry, U. S. Public Health Service, Div. of Air Pollution (Sept. 1964).

211. Pendray and Co., N.Y.C., Opinion Survey on Odors and Fumes as Air Pollution Problems (March 29, 1955).

212. Permissible Immission Concentrations of Hydrogen Sulphide, VDI 2107 (April 1960).

213. Petri, H., Assessing the Health Hazards of Gaseous Air Pollutions, Staub 25:50 (1965).

214. The Petroleum Refining Industry - Air Pollution Problems and Control Methods. Informative Report No. 1., J. Air Pollution Control Assoc. 14(1):51 (1964).

215. Pirrone, F., Odor and Chemical Structure, Rivista Ital. Essenze Profumi 11:2 (1929).

216. Plotkinova, M. M., Acrolein Pollution in the Atmosphere, Gigiena i Sanit. 22:10 (1957).

217. Popov, I. N., Y. F. Cherkasov, and O. L. Trakhtman, Determination of Sulfur Dioxide Odor Threshold Concentration, U.S.S.R. Literature on Air Pollution and Related Occupational Diseases 3:102 (1960).

218. Posselt, H. S., and A. H. Reidies, Odor Abatement with Potassium Permanganate Solutions, Ind. Eng. Chem. Prod. Res. Develop. 4:48 (1965).

219. Post, N., Counteraction of Sewage Odors, Sewage Ind. Wastes 28(2):221 (1956).

220. "Prepared Statement of Andrew W. Miller, Mayor of Steubenville, Ohio," in Air Pollution - 1968, Part 1, Hearings Before the Subcommittee on Air and Water Pollution of the Committee on Public Works, U. S. Senate, p. 75 (1968).

221. Public Awareness and Concern with Air Pollution in the St. Louis Metropolitan Area, U. S. Public Health Service, Div. of Air Pollution, Washington, D. C. (May 1965).

222. Pulp, Paper and Board Branch, Forest Product and Packing Division, Business and Defense Services Administration, Department of Commerce, Washington, D. C.

223. Ramsey, W., Nature 26:187 (1882).

224. Randolph, T. G., Allergic Headache, J. Am. Med. Assoc. 126:430 (1944).

225. Rappaport, B. Z., and R. Hecht, Wood Smoke as a Cause of Asthma, J. Am. Med. Assoc. 113:1024 (1939).

226. Rappaport, B. Z., and M. M. Hoffman, Urticaria due to Aliphatic Aldehyde, J. Am. Med. Assoc. 116:2656 (1941).

227. Reckner, L. R., W. E. Scott, and W. F. Biller, The Composition and Odor of Diesel Exhaust, Proc. Am. Petrol. Inst. 45:133 (1965).

228. Reed, R. J., and S. M. Truitt, Selecting Incinerator Smoke and Odor Burners, Air Repair 4(3):109 (1954).

229. Report on Bi-State Study of Air Pollution in the Chicago Metropolitan Area, Indiana State Board of Health and Illinois Department of Public Health (1957-1959).

230. Report on Interstate Air Pollution in the Shoreham, Vermont-Ticonderoga, New York Area, Abatement Branch, U. S. Public Health Service, Div. of Air Pollution (Nov. 1965).

231. Restricting Emission of Hydrogen Sulphide and Other Sulphur Containing Compounds, Except Sulphur Dioxide, from Gas Generators in Coke, Gas, and Coal-Constituent Processing Plants, The Anthracite-Mining Association, Essen, Germany, VDI No. 2109 (May 1960).

232. Roberts, D. X., The Four-Cycle Diesel. Presented at Meeting of Canadian Transit Association, Toronto, Canada (March 1960).

233. Robinson, E., and R. C. Robbins, Sources, Abundance and Fate of Gaseous Atmospheric Pollutants. Final Report. Stanford Res. Inst. Project PR-6755 (Feb. 1968).

234. Roderick, W. R., Current Ideas on the Chemical Basis of Olfaction, J. Chem. Educ. 43(10):510 (1966).

235. Ronald, D., Handbook of Offensive Trades (London: William Hodge and Co., 1935).

236. Rosen, A. A., J. B. Peter, and F. M. Middleton, Odor Thresholds of Mixed Organic Chemicals, J. Water Pollution Control Federation 34(1):7 (1962).

237. Rosen, F. L., and A. Levy, Bronchial Asthma Due to Allergy to Tobacco Smoke in an Infant. A Case Report, J. Am. Med. Assoc. 144:620 (1950).

238. Rossano, A. T., Sources of Community Air Pollution - Atmospheric Pollution. Presented Before the Interdisciplinary Conference on Atmospheric Pollution, Santa Barbara, Calif. (June 1959).

239. Rounds, F. G., and H. W. Pearsall, Diesel Exhaust Odor, Its Evaluation and Relation to Exhaust Gas Composition, Presented at Society of Automotive Engineers National Diesel Engine Meeting, Chicago, Ill. (Nov. 1956).

240. Rowe, A. H., "Elimination Diets and the Patient's Allergies," in Handbook of Allergy, 2nd ed. (Philadelphia: Lea and Febiger, 1944).

241. Ruzicka, L., Die Grundlagen der Geruchschemie, Chem. Ztg. 44 (1920).

242. Sableski, J. J., The Federal Air Pollution Control Program as it Relates to the Kraft Pulping Industry. Presented at 52nd Annual Meeting of Technical Association of the Pulp and Paper Industry, New York, N.Y. (Feb. 1967).

243. Sableski, J. J., Odor Control in Kraft Mills, A Summary of the State of the Art, U. S. Public Health Service, National Center of Air Pollution Control, Cincinnati, Ohio (May 10, 1967).

244. Sandomirsky, A. G., et al., Fume Control in Rubber Processing by Direct-Flame Incineration. Presented at the Air Pollution Control Association 59th Annual Conference, San Francisco, Calif. (June 20-24, 1966).

245. Santry, I. W., Jr., Hydrogen Sulfide Control Measures, J. Water Pollution Control Federation 38(3):459 (1966).

246. Salter, H. H., Asthma: Its Pathology and Treatment (New York: William Wood, 1882).

247. Schirren, C. G., Diacetyl, Allergen Contained in Tobacco Smoke, Wood Smoke and Coffee Aroma, Hautarzt 2:324 (1951).

248. Schueneman, J. J., M. D. High, and W. E. Bye, Air Pollution Aspects of the Iron and Steel Industry, *U. S. Public Health Serv. Publ. 999-AP-1* (1963).

249. Segeler, G. C., The Gas Industry and Its Contribution to Air Pollution Control. Presented at the 54th Annual Meeting of Air Pollution Control Association (June 1961).

250. Shah, I. S., Air Pollution - Pulp Plant Pollution Control, *Chem. Eng. Progr*. *64*(9):66 (1968).

251. Sinitsyna, E. L., Investigations Into Certain Aspects of the Health of People Working in the Main Shops of Tanneries, *Hyg. Sanitation* *30*(6):336 (1965).

252. Sinks, F. W., Two-Cycle Diesel Odor Control - A Progress Report, Presented at Meeting of Canadian Transit Association, Toronto, Canada (March 1960).

253. Smith, W. S., Atmospheric Emissions from Fuel Oil Combustion, An Inventory Guide, Environmental Health Series, Public Health Service, Division of Air Pollution (1962).

254. Smith, W. S., J. J. Schueneman, and L. D. Zeidberg, Public Reaction to Air Pollution in Nashville, Tennessee, *J. Air Pollution Control Association* *14*(10):418 (Oct. 1964).

255. Stalker, W. W., Defining the Odor Problem in a Community, *J. Am. Ind. Hyg. Assoc*. *24*:600 (1963).

256. Standard Method for Measurement of Odor in Atmosphere (Dilution Method), American Society for Testing Materials Standard Method D 1391-57.

257. Stayzhkin, V. M., Hygienic Determination of Limits of Allowable Concentrations of Chlorine and Hydrochloride Gases Simultaneously Present in Atmospheric Air, Translated by B. S. Levine, *U.S.S.R. Literature on Air Pollution and Related Occupational Diseases* *9*:55 (1962).

258. Stern, A. C. (*Ed*.), *Air Pollution*, vol. 1, 2nd ed. (New York: Academic Press, pp. 484, 520, 1968).

259. Stern, A. C. (*Ed*.), *Air Pollution*, vol. II, 2nd ed. (New York: Academic Press, p. 325 1968).

260. Stern, A. C., (Ed.), Air Pollution, vol. III, 2nd ed. (New York: Academic Press, pp. 91, 114-115, 258-261, 272-275,280-287,514-515 1968).

261. Sternberg, L., and A. H. Sorrell, Occupational Asthma and Vasomotor Rhinitis, N.Y. State J. Med. 41:1619 (1941).

261a. Stevens, R. K., A. E. O'Keeffe, J. D. Mulik, and K. J. Krost, Gas Chromatography of Reactive Sulfur Gases in Air at the Parts-Per-Billion Level. 1. Direct Chromatographic Analysis, Preprint. National Air Pollution Control Administration, Cincinnati, Ohio (1969).

262. Sticker, G., Das Heffieber und Verwandte Storungen (Vienna: Holder 1912).

263. Stockman, R. L., and D. Anderson, Physiologic, Economic, and Nuisance Effects of Emissions from Sulfate Pulping in Proc. Intern. Conf. on Atmospheric Emissions from Sulfate Pulping, Sanibel Island, Fla. (April 28, 1966).

264. Stokinger, H. E., and D. L. Coffin, "Biological Effects of Air Pollutants," in Air Pollution, vol. 1, 2nd ed., A. C. Stern, Ed. (New York: Academic Press, p. 484, 1968).

265. Strauss, W., The Development of a Condenser for Odor Control from Dry Rendering Plants, J. Air Pollution Control Assoc. 14(10):424 (1964).

266. Strimbeck, D. C., Clean Gas From Coal May be Economical Fuel for Gas Turbines, Power Engineering (July 1966).

267. Studies of Potential Exposures of Railroad Trainmen to Diesel Exhaust Gases and to Dust from Locomotive Sanders, Bureau of Adult Health, California Dept. of Public Health (1957).

268. A Study of Air Pollution in the Interstate Region of Lewiston, Idaho, and Clarkston, Washington, Environmental Health Series, U. S. Public Health Service, Cincinnati, Ohio (Dec. 1964).

269. Stutz, C. N., Treating Parathion Wastes, Chem. Eng. Progr. 62(101) (1966).

270. Sullivan, D. C., D. F. Adams, and F. A. Young, "Design of an Odor Perception and Objectionability Threshold Test Facility" in Atmospheric Environment, vol. 2 (London: Pergamon Press, pp. 121-133, 1968).

271. Sulzberger, M. D., and R. L. Baer, Office Immunology, (Chicago: Year Book Publishers, 1947).

272. Summer, W., Methods of Air Deodorization (Amsterdam: Elsevier, 1963).

273. Survey of Operating Refineries in the U.S.A., Oil Gas J. 67(12):(1969).

274. Sussman, V. H., and J. J. Mulhern, Air Pollution From Coal Refuse Disposal Areas, J. Air Pollution Control Assoc. 14(7):(1964).

275. Sutton, R., Discussion to Pels, Arch. Dermatol. Syph. 16:639 (1927).

276. Szentivanyi, A., G. Flipp, and G. Legeza, Investigations on Tobacco Sensitivity: Tobacco Sensitivity as Occupational Disease, Acta Med. Hung. 3:175 (1952).

277. Teller, A. J., Odor Abatement in the Rendering and Allied Industries, J. Air Pollution Control Assoc. 13(4):148 (1963).

278. Teudt, H., Origin in Molecules of Odoriferous Substances, Prometheus 30:201 (1919).

279. Thomas, J. W., and V. P. Wecksten, Allergy in Relation to the Genito-Urinary Tract, Ann. Allergy 2:396 (1944).

280. Threshold Limit Values for 1967, Adopted at the 29th Annual Meeting of the American Conference of Governmental Industrial Hygienists, Chicago, Ill. (May 1-2, 1967).

281. Tkach, N. Z., Combined Effect of Acetone and Acetophenone in the Atmosphere, Gigiena i Sanit. 30(8):(1965).

282. Toliver, W. H., Sr., and M. L. Morris, Chemical Analysis of Permanent and Organic Gases in a 30-Day Manned Experiment, AMRL-TR066-13, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio (March 1966).

283. Tschirch, A., Chem. Zentr. 3:190 (1921).

284. Turk, A., Odor Control Methods: A Critical Review, Symposium on Odor, Special Tech. Publ. No. 164, American Society for Testing Materials, pp. 69-80 (1954).

285. Turk, A., Selection and Training of Judges for Sensory Evaluation of the Intensity and Character of Diesel Exhaust Odors, City College of the City of New York. U. S. Public Health Service Publ. 999-AP-32 (1967).

286. Ullrich, A. H., and R. J. Ruff, Oxidation of Sewage Odors, Water Sewage Works 106:395 (1959).

287. Ungerer, W. G., and R. B. Stoddard, Ungerer's Bull. 3(1): 7 (1922).

288. Urbach, E., Odors (Osmyls) as Allergenic Agents, J. Allergy 13:387 (1942).

289. Veninga, T. S., Toxicity of Ozone in Comparison with Ionizing Radiation, Strahlentherapie 134(3):469 (1967).

290. Viessman, W., Control of Odors in Working Environments, Occupational Health Rev. 17(2):12 (1965).

291. Viessman, W., Gaseous Air Pollution - Its Sources and Control, Air Eng. 10(7):14 (1968).

292. Von Bergen, J., Latest Methods You Can Use for Industrial Odor Control, Chem. Eng. (Aug. 1957).

293. Walsh, R. T., The Inedible Rendering Industry, Informative Report Prepared for the TI-2, Chemical Industries Committee of the Air Pollution Control Association (1968).

294. Weisburd, M. I. (Ed.) Air Pollution Control Field Operations Manual, U. S. Public Health Service, Div. of Air Pollution, Washington, D. C. (1962).

295. Welsh, G. B., Air Pollution in the National Capital Area, U. S. Public Health Service Publ. 955 (1962).

296. Wenzel, H. F. J., and O. U. Ingruber, Controlling Problems of Air and Water Contamination, Paper Trade J. pp. 42-47 (Jan. 16, 1967).

297. Wetmiller, R. S., and L. E. Endsley, Effect of Diesel Fuel on Exhaust Smoke and Odor, Soc. Automotive Engrs. J. (Dec. 1942).

298. Wilby, F. V., Variation in Recognition Odor Threshold of a Panel, J. Air Pollution Control Assoc. 19(2):96 (1969).

299. Williams, A. F., Oil Firing and Odour Problems, Presented to the S.V.M.T. Meeting, Zurich, on September 11, 1964, Esso Research Limited, Abingdon, England (1964).

300. Winslow, C. E. A., and L. P. Herrington, Am. J. Hyg. 23:143 (1936).

301. Winslow, C. E. A., and G. T. Palmer, Proc. Soc. Exptl. Biol. Med. 21:141 (1915).

302. WMAL News Broadcast, Washington, D. C. (May 24, 1969).

303. Wohlbier, F. H., and G. W. P. Rengstorff, Preliminary Study of Gas Formation During Blast-Furnace Slag Granulation with Water. Presented at the Annual Meeting of the Air Pollution Control Association (June 26, 1968).

304. Woker, G., The Relations Between Structure and Smell in Organic Compounds, J. Phys. Chem. 10:455 (1906).

305. Wright, R. H., Odour and Chemical Constitution, Nature 173:831 (1954).

306. Wright, R. H., Molecular Structure and Organoleptic Quality, Soc. of Chem. Ind. (London) Monograph 1: 91 (1957).

307. Wright, R. H., Nature 198:783 (1963).

308. Yaakmees, V. A., The Establishment of the Maximum Permissible Concentration of Shale Gasoline in the Atmosphere, Hyg. Sanitation 31(1,2,3):295 (1966).

309. Young, H. D., Diesel Engine Exhaust Smoke as Influenced by Fuel Characteristics. Presented at the Society of Automotive Engineers Annual Meeting, Detroit, Mich. (1948).

310. Zakon, S. J., and J. B. Kahn, Urticaria from Perfumes, Arch. Dermatol. Syph. 52:11 (1945).

311. Zohn, B., An Unusual Case of Spinach Hypersensitiveness, J. Allergy 8:381 (1937).

312. Zwaardemaker, H., Fortschritte der Medicin 19:721 (1889).

313. Zwaardemaker, H., Odeur et chimisme, Arch. Neerl. Physiol. 6:336 (1922).

## OTHER REFERENCES

Adams, D. F., European Air Pollution, 1964, *J. Air Pollution Control Assoc*. *15*(8):375 (1965).

Adams, D. F., A Survey of European Kraft Mill Odor Reduction System, *Tappi* *48*(5):83A (1965).

Adams, D. F., and R. K. Koppe, An Air Quality Study in the Vicinity of Lewiston, Idaho and Clarkston, Washington, *J. Air Pollution Control Assoc*. *16*(6):314 (1966).

Adams, D. F., and F. A. Young, Kraft Odor Detection and Objectionability Thresholds. Preprint (1965).

Albinus, G., Reducing the Emission of Small Waste Incinerators by Structural and Control Measures, *Staub* *25*(11):17 (1965).

Apartment House Incinerators, Rept. No. 29 to the Federal Housing Administration, *Natl. Acad. Sci. - Natl. Res. Council Publ. 1280*, Washington, D. C. (1965).

Banner, A. P., and E. M. Ilgenfritz, Disposal of Coal Tar Pitch Distillate Obtained from Carbon Baking Furnace by Catalytic Combustion, Air Pollution Control Association Meeting (June 1963).

Barnebey, H. L., Removal of Exhaust Odors from Solvent Extraction Operation by Activated Charcoal Adsorption, *J. Air Pollution Control Assoc*. *15*(9):422 (1965).

Bethge, O., and L. Ehrenborg, Identification of Volatile Compounds in Kraft Mill Emissions, *Svensk Papperstid*. *70*:347 (1967).

Betz, E., Odour Control by Catalytic Combustion, *Proc. Clean Air Conf. 1965*, London, England, Oct. 26-29, 1965.

Bolduc, M. J., R. K. Severs, and G. L. Brewer, Test Procedures for Evaluation of Industrial Fume Converters, *Air Eng*. *8*(2): 20 (1966).

Bovier, R. F., *et al*., Solving a Valley Air Pollution Problem. Presented at the 54th Annual Meeting, Air Pollution Control Association, New York, June 15, 1961.

Brewer, G. L., Odor Control for Kettle Cooking, J. Air Pollution Control Assoc. 13:167 (1963).

Brink, D. L., J. F. Thomas, and D. L. Feuerstein, Malodorous Products from the Combustion of Kraft Black Liquor. II. Analytical Aspects, Tappi 50(6):276 (1967).

Brink, D. L., J. F. Thomas, and K. H. Jones, Malodorous Products from the Combustion of Kraft Black Liquor, III. A Rationale for Controlling Odors, University of California, Forest Products Laboratory and Sanitary Engineering Research Laboratory, Richmond, Calif. (1967).

Buxton, W. H., and M. W. Lapointe, Chemical Recovery and Odor Abatement on a Kraft Recovery Furnace, Tappi 48(5):112A (1965).

Cady, F. H., A Kraft Mill Waste Chlorine Gas Recovery Scrubber. Presented at the Second Annual Meeting, Pacific Northwest International Section, Air Pollution Control Association, Portland, Oreg. (Nov. 5-6, 1964).

Cave, G. C. B., The Collection and Analysis of Odorous Gases From Kraft Pulp Mills, Part I: Theoretical Considerations, Tappi 46(1):1 (1963).

Cave, G. C. B., The Collection and Analysis of Odorous Gases From Kraft Pulp Mills, Part II: A Laboratory Study of the Collection of Pollutants for Analysis, Tappi 46(1):5 (1963).

Cave, G. C. B., The Collection and Analysis of Odorous Gases From Kraft Pulp Mills, Part III: The Analysis of Collected Pollutants by Gas Chromatography, Tappi 46(1):11 (1963).

Cave, G. C. B., The Collection and Analysis of Odorous Gases From Kraft Pulp Mills, Part IV: A Field Kit for the Collection of the Pollutants, and Methods for Their Analysis, Tappi 46(1):15 (1963).

Cederlof, R., et al., On the Determination of Odor Thresholds Air Pollution Control--An Experimental Field Study on Flue Gases From Sulfate Cellulose Plants, J. Air Pollution Control Assoc. 16(2):92 (1966).

Challis, J. A., Three Industrial Incineration Problems, 1966 Natl. Incinerator Conf. Proc., pp. 208-218 (1966).

Chizhikov, V.A., Production of Certain Pathological Manifestations as a Conditioned Reflex Induced by Exposure to Low Concentrations of Toxic Substances, Hyg. Sanitation 32(4,5,6):323 (1967).

Collins, T. T., Jr., New Systems Proposed for Kraft Mill Odor Control and Heat Recovery, Paper Trade J. p. 34 (1965).

A Compilation of Ambient Air Quality Standards and Objectives, U. S. Public Health Service, Cincinnati, Ohio (1966).

Cook County Air Pollution Control Ordinance, The Air Pollution Control Bureau, Chicago, Ill. (April 30, 1963).

DeHaas, G. G., and L. C. Amos, Recovery Systems for Mixed Kraft and Sulfite Liquors, Tappi 50(3):75A (1967).

Devorkin, H., et al., Source Testing Manual, Air Pollution Control District, County of Los Angeles (1965).

Douglass, I. B., Some Chemical Aspects of Kraft Odor Control, Paper No. 67-11C, University of Maine, Orono, Maine (1967).

Douglass, I. B., The Chemistry of Pollutant Formation in Kraft Pulping, in Proc. Intern. Conf. on Atmospheric Emissions from Sulfate Pulping, Sanibel Island, Fla. (April 28, 1966).

Dravnieks, A., B. Krotoszynski, and J. Stockham, Sampling and Measurement of Odorous Gaseous Pollutants in Industrial Exhaust and Air, IIT Research Institute, Chicago, Ill.

Duerden, C., A Problem of Fume Emission, Public Health Inspector (London) 74:21 (1965).

Eliminating Smell from a Refinery, Petroleum (London) 29(4): 148 (1966).

Feuerstein, D. L., J. F. Thomas, and D. L. Brink, Malodorous Products from the Combustion of Kraft Black Liquor. I. Pyrolysis and Combustion Aspects, Tappi 50(6):258 (1967).

Fiske, P. R., City's Plans to Sweeten Air Are Rendered Useless, Washington Post, Washington, D. C. (April 10, 1969).

Frye, C. G., and J. F. Mosby, "Kinetics of Hydrodesulfurization," Chem. Eng. Progr. 63(9):66 (1967).

Gas Chromatography Applied to Atmospheric Kraft Odors, Final Report, Grant No. AP-00023, College of Engineering Research Division, Washington State University, Pullman, Wash. (Oct. 28, 1966).

Gasteiger, E. L., and S. A. Helling, X-ray Detection by the Olfactory System: Ozone as a Masking Odorant, Science 154:1038 (1966).

The Greater Johnstown Air Pollution Survey, Pennsylvania Dept. of Health, Div. of Air Pollution Control (June 22, 1966).

Gumerman, R. C., and D. A. Carlson, Methyl Mercaptan Removal by Soil Filtration. Presented at the Annual Meeting of the Pacific Northwest International Section, Air Pollution Control Association, Vancouver, B. C. (Nov. 2-4, 1965).

Harkness, A. C., and F. E. Murray, Gas Phase Oxidation of Methyl Mercaptan, Intern.J. Air Water Pollution 10:245 (1966).

Harris, L. S., Fume Scrubbing with the Ejector Venturi System, Chem. Eng. Progr. 62(4):55 (1966).

Harris, R. L., Jr., Public Health Service Air Pollution Abatement Activities. Presented at the Air Pollution Control Association Central Section Meeting, Cincinnati, Ohio (Sept. 28-30, 1966).

Henshaw, T. B., Odor Control at a 2,4-D Production Plant, Chipman Chemical Co., Inc., Portland, Oregon. Presented at the Air Pollution Control Association, Pacific Northwest International Section, Portland, Oreg. (Nov. 6, 1964).

Hildebrandt, P. W., and R. L. Stockman, Air Quality in Clark County, Washington, Air Sanitation and Radiation Control Section, Div. of Environmental Health, State of Washington Dept. of Health (1965).

Hochheiser, S., S. W. Horstman, and G. H. Tate, Jr., A Pilot Study of Air Pollution in Birmingham, Alabama, U. S. Public Health Service, Cincinnati, Ohio (May 1962).

Holland, H. R., Air Quality Control by Petroleum Refiners. Presented at the Annual Meeting, Pacific Northwest International Section of the Air Pollution Control Association, Vancouver, B. C. (Nov. 2, 1965).

Honma, M., and E. H. Kawasaki, Thermal Degradation of Polymeric Materials. II. Toxicity Evaluations of Some Gases Evolving from Epon 828 + LP 33 Composite Polymer, Lockheed Missiles and Space Div., Sunnyvale, Calif. (1961).

HPAC Engineering Data File, Industrial Air Pollution Control, *Heating, Piping Air Conditioning*, p. 179 (March 1967).

Huey, N. A., L. C. Broering, and C. W. Gruber, Odor Measurement Techniques, II, U. S. Public Health Service, Community Air Pollution Demonstration Project Grant A-59-541, Second Year Final Report (Dec. 1959).

Huguet, J. H., *et al.*, Africa, *J. Air Pollution Control Assoc.* *16*(11):574 (1966).

Hurn, R. W., and D. E. Seizinger, Air Pollutant Inventory Enter the Diesel, *Proc. Am. Petrol. Inst.* *45*(111): 127 (1965).

Intensities of Odors and Irritating Effects of Warning Agents for Inflammable and Poisonous Gases, U. S. Bureau of Mines, Tech. Paper 480 (1930).

Johnson, E., Nuisance from External Environmental Factors and Norms for Their Evaluation, *Nord. Hyg. Tidskr.* *XLIV*:69 (1963).

Kendall, D. A., and A. J. Neilson, Odor Profile Studies of Effluent Waste Waters from Seven Refineries, *Proc. Am. Petrol. Inst.* *44*(3):62 (1964).

Klisenko, M. A., *et al.*,The Determination of Phthalophos and Phozalon in Air, *Hyg. Sanitation* *32*(7,8,9):232 (1967).

Knott, K. H., and S. Turkolmez, Krupp Rotary Brush Scrubber for the Control of Gas Vapour, Mist and Dust Emissions, *Krupp Tech. Rev.* *24*(1):25 (1966).

Koppe, R. K., and D. F. Adams, Gas-Phase Chlorination of Kraft Pulp Mill Gases, Tappi 51(5):193 (1968).

Kosmodamianskays, D. M., Effect of Atmospheric Pollution Upon The Population's Health, Hyg. Sanitation 33(1,2,3):265 (1968).

Landry, J. E., Black Liquor Oxidation Practice and Development--A Critical Review, Tappi 46(12):766 (1963).

Larsen, R. I., "Future Air Quality Standards and Industrial Control Requirements," in Proceedings of the Third National Conference on Air Pollution, Washington, D. C. (Dec. 12-14, 1966).

Lenz, W., and A. Tirado, Mexico Kraft Mill Uses Observers to Check Its Odor Control Program, Paper Trade J. (1966).

Lindvall, T., Bestamming av luktande luftfororeningar, Nord. Hyg. Tidskr. 47(2):41 (1966).

Lloyd, D. H., A Note on Factory Process Smells and Toxic Hazards, Sheet Metal Ind. 44(481):311 (1967).

Longwell, D. H., The National Council for Stream Improvement, Air Pollution Studies. Presented at the Air Pollution Control Association Pacific Northwest International Section, Oregon State Univ. (Nov. 8, 1964).

Ludwig, J. H., Status of Vehicle Emissions in Air Pollution. Presented at the Eighth Annual Environmental Health Institute sponsored by the Colorado Association of Sanitarians, Denver, Col. (April 26, 1963).

Ludwig, J. H., Seminar on Air Pollution by Motor Vehicles, Division of Air Pollution, U. S. Public Health Service, Cincinnati, Ohio (1964).

Matteson, M. J., L. N. Johanson, and J. L. McCarthy, Sekor II: Stream Stripping of Volatile Organic Substances from Kraft Pulp Mill Effluent Streams, Tappi 50(2):86 (1967).

Mazitova, R. M., et al., Olfactory Sense and Its Simulation by Modeling, Joint Publication Research Service 38:994, U. S. Department of Commerce, Washington, D. C. (1966).

McCabe, L. C., and J. S. Lagarias, Air Pollution and the Paint Industry," J. Paint Technol. 38(495):210 (1966).

McKean, W. T., Jr., B. F. Hrutfiord, and K. V. Sarkanen, Kinetic Analysis of Odor Formation in the Kraft Pulping Process, Tappi 48(12):699 (1965).

McKee, J. E., Air Pollution Control - Economic Impact of Growing Problem, Trust and Estates Magazine (Feb. 1964).

Middleton, J. T., Future Air Quality Standards and Motor Vehicle Emission Restrictions. Presented at the National Conference on Air Pollution, Washington, D. C. (Dec. 12-14, 1966).

Morrow, P. E., Adaptations of the Respiratory Tract to Air Pollutants, A.M.A. Arch. Environ. Health 14:127 (1967).

MP&E's Guide to Air Pollution Control Methods, Mod. Power Eng. 6(6):63 (1966).

Murray, F. E., The Control of Kraft Mill Odors, Occupational Rev. (Ottawa) 17(2):23 (1963).

Odor Control for Kettle Cooking, J. Air Pollution Control Assoc. 13:167 (1963).

"Odors Associated with Atmospheric Particulate Matter," in Air Quality Criteria for Particulate Matter, U. S. Public Health Service, National Air Pollution Control Administration, Washington, D. C. (1969).

Ono, S., Odor Produced and Its Control by Wet Scrubbing in Night Soil Treatment Plant, Trans. Soc. Heating, Air Conditioning Sanitary Eng. (Japan) 3:42 (1965).

Patty, F. A., "Sampling and Analysis of Contaminants," in Industrial Hygiene and Toxicology, 2nd ed. (New York: Interscience, p. 174, 1963).

Petri, H., The Effects of Hydrogen Sulfide and Carbon Disulfide, Staub 21(2):64 (1961).

Phelps, A. H., Jr., and J. F. Byrd, Odor and the Socially Acceptable Industry. Presented at Symposium on Industrial Air Pollution Control, Part 1, 59th Annual Meeting, Detroit, Mich. (Dec. 4-8, 1966).

A Pilot Study of Air Pollution in Jacksonville, Florida, August to September 1961, U. S. Public Health Service, Cincinnati, Ohio (1962).

Porter, E. V., An Odor Survey of the Two Kansas Cities, A Cooperative Study by the Cities of Kansas City, Kansas, and Kansas City, Missouri, and the U. S. Dept. of Health, Education and Welfare (1965).

Reckner, L. R., _et al_., Progress Report on Diesel Exhaust Composition, Odor and Eye Irritation, for Period May 1, 1962 to February 15, 1963, Scott Research Laboratories, Inc., Perkasie, Pa. and San Bernardino, Calif. (March 1963).

Reckner, L. R., _et al_., Final Report on Diesel Exhaust, Composition, Odor and Eye Irritation, for Period December 3, 1965 to December 2, 1966, Scott Research Laboratories, Inc., Perkasie, Pa. (1967).

Regulation and Control of Air Pollutants from the Stock Yards Area, Department of Air Pollution Control, City of Chicago, Chicago, Ill.

Rendering Plant Flow Sheet, Process Flow Sheets and Air Pollution Controls, American Conference of Governtmental Industrial Hygienists, Committee on Air Pollution (1961).

Rendering Plants, Information Bulletin No. 1A, Oregon State Sanitary Authority, Oregon State Board of Health (Oct. 1964).

Rihm, A., Jr., New York State's Ambient Air Quality Objectives System. Presented at National Power Conference of the American Society of Mechanical Engineers, Albany, N. Y. (Sept. 20, 1965).

Riverside County, Air Pollution Control District, Rules and Regulations, Chapter 2, Division 20, Health and Safety Code of the State of California (1962).

Romano, A. H., and R. S. Safferman, Studies on Actinomytes and Their Odors, _J. Am. Water Works Assoc_. _55_(2):169 (1963).

Rosen, A. A., R. T. Skeel, and M. B. Ettinger, Relationship of River Water Odor to Specific Organic Contaminants, _J. Water Pollution Control Federation_ _35_(6):777 (1963).

Rose, A. H., Jr., Diesel Smoke Problem. Presented at the 1963 Metropolitan Conference on Air Pollution Control, Cincinnati, Ohio (Oct. 22, 1963).

Ryazanov, V. A., "A Summary of 1961 Studies in the Field of Limits of Allowable Concentrations of Atmospheric Air Pollutants," in Limits of Allowable Concentrations of Atmospheric Pollutants, Book 7, Washington, D. C. (1963-64).

Sableski, J. J., Community Odor Surveys and Evaluation. Presented at the Mid-Atlantic States Section Meeting, Air Pollution Control Association, Wilmington, Del. (Nov. 1965).

Safferman, R. S., et al., Earthy-Smelling Substance from a Blue-Green Alga, Environ. Sci. Technol. 1(5):429 (1967).

Salzenstein, M. A., Industrial Performance Standards for Zoning a Current Review, Paper No. 65-12, Polytechnic Inc., Chicago, Ill.

Sanderson, H. P., P. Bradt, and M. Katz, A Study of Air Pollution in Saint John, New Brunswick, Canada. Presented at 58th Annual Meeting, Air Pollution Control Association, Toronto, Canada (June 20-24, 1965).

Sanderson, H. P., R. Thomas, and M. Katz, Limitations of the Lead Acetate Impregnated Paper Tape Method for Hydrogen Sulfide, J. Air Pollution Control Assoc. 16(6):328 (1966).

Sarkanen, K. V., Effect of New Process Technology on Air Pollution Potential, Proc. Intern. Conf. on Atmospheric Emissions from Sulfate Pulping, Sanibel Island, Fla. (April 28, 1966).

Schneider, R. A., The Sense of Smell in Man--Its Physiologic Basis, New Engl. J. Med. 277(6):299 (1967).

Schneider, R. A., C. E. Schmidt, and J. P. Costiloe, Relation of Odor Flow Rate and Duration of Stimulus Intensity Needed for Perception, J. Appl. Physiol. 21(1):10 (1966).

Schueneman, J. J., and C. G. Beard, II, Charleston-Kanawha Valley Air Pollution Study--A Description. Presented at the 55th National Meeting, American Institute of Chemical Engineers, Houston, Tex. (Feb. 7-11, 1965).

Schueneman, J. J., D. R. Goodwin, and S. T. Cuffe, How the Federal Government Looks at Air Pollution, Mod. Castings 47:43 (1965).

Shah, I. S., New Flue-Gas Scrubbing System Reduces Air Pollution, Chem. Eng. 74(7):84 (1967).

Springer, K. J., Investigation of Diesel Powered Vehicle Odor and Smoke, Part 2, Monthly Progress Report No. 3, for the period March 15 - April 15, 1967. Southwest Research Institute, San Antonio, Tex. (May 3, 1967).

Springer, K. J., Investigation of Diesel Powered Vehicle Odor and Smoke, Part 2, Monthly Progress Report No. 4, for the period April 15, 1967 - May 15, 1967. Southwest Research Institute, San Antonio, Tex. (May 26, 1967).

Springer, K. J., and R. C. Stahman, An Investigation of Diesel Powered Vehicle Odor and Smoke, A Progress Report, National Petroleum Refiners Association. Presented at the Fuels and Lubricants Meeting, Philadelphia, Pa. (Sept. 15-16, 1966).

Squires, A. M., Air Pollution: The Control of $SO_2$ From Power Stacks. Part IV: Power Generation with Clean Fuels, Chem. Eng. 74(26):101 (1967).

Status of Present Investigations and Future Research Needs in Atmospheric Pollution Control, Atmospheric Pollution Technical Bulletin No. 29, National Council for Stream Improvement, New York, N. Y. (1966).

Stenburg, R. L., Atmospheric Emissions from Paint and Varnish Operations. Part 1, Paint Varnish Prod. 49:61 (1959).

Strauss, W., Odour Control for the Process Industries, Chem Process Eng. 46(3):133 (1965).

Suggested Construction and Operational Techniques for the Development of Good Sanitation Practices in Texas Rendering Plants, Texas State Department of Health, Austin, Tex. (1952).

Sullivan, J. L., F. L. Kafka, and L. M. Ferrari, An Evaluation of Catalytic and Direct Fired Afterburners for Coffee and Chicory Roasting Odors, J. Air Pollution Control Assoc. 15(12):583 (1965).

Sullivan, J. H., D. H. Robertson, and C. Merritt, Jr., The Determination of the Volatile Components of Foodstuffs. III. Coffee Aroma, Quartermaster Research and Engineering Center, Natick, Mass. (1959).

Summer, W., Odour Destruction, J. Inst. Heating Ventilating Engrs. 34:229 (1966).

Suzuki, Y., K. Nishiyama, and M. Oe, Studies on the Prevention of Public Nuisance by the Exhaust Gases from the Kraft Pulp Mill, Tokushima J. Exptl. Med. 11:120 (1964).

Tarkhova, L. P., Materials for Determining the Maximum Permissible Concentration of Chlorobenzol in Atmospheric Air, Hyg. Sanitation 30:327 (1965).

Thoen, G. N., et al., Effect of Combustion Variables on the Release of Odorous Compounds from a Kraft Recovery Furnace, Tappi 51(8):329 (1968).

Thomas, E., S. Broaddus, and E. W. Ramsdell, Air Pollution Abatement at S. D. Warren's Kraft Mill in Westbrook, Me., Tappi 50(8):81A (1967).

Thomas, M. D., "The Present Status of the Development of Instrumentation for the Study of Air Pollution," in Proc. 2nd Natl. Air Pollution Symp. (1952).

Tucker, D., Physical Variables in the Olfactory Stimulation Process, J. Gen. Physiol. 46(3):453 (1963).

Turk, A., Approaches to Sensory Odor Measurement, Ann. N. Y. Acad. Sci. 116:564 (1964).

Turk, A., Measuring and Controlling Odors, Heating, Piping Air Conditioning 40(1):201 (1968).

Vaughn, J. C., Tastes and Odors in Water Supplies, Environ. Sci. Technol. 1(9):703 (1967).

Venezia, R. A., The Interstate Air Pollution Study, St. Louis-East St. Louis Metropolitan Area, Presented at the Missouri Public Health Association Convention, Kansas City, Mo. (May 11, 1965).

Witheridge, W. N., "Ventilation," in Industrial Hygiene and Toxicology, 2nd ed., F. A. Patty, Ed. (New York: Interscience, 1963).

Wohlers, H. C., Recommended Procedures for Measuring Odorous Contaminants in the Field, J. Air Pollution Control Assoc. 17(9):609 (1967).

Wright, R. H., New Work in Kraft Mill Odor Control, J. Air Pollution Control Assoc. 13(3):101 (1963).

# APPENDIX A

APPENDIX A

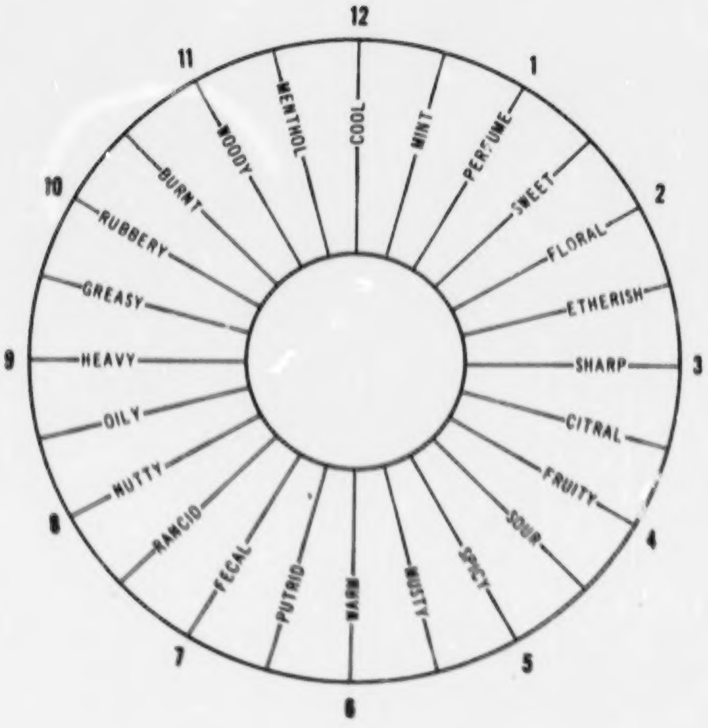

12
COOL
MINT
1
PERFUME
SWEET
2
FLORAL
ETHERISH
3
SHARP
CITRAL
FRUITY
4
SOUR
SPICY
5
MUSTY
WARM
6
PUTRID
FECAL
7
RANCID
NUTTY
8
OILY
HEAVY
9
GREASY
RUBBERY
10
BURNT
WOODY
11
MENTHOL

FIGURE 1

Odor Quality Chart [96]

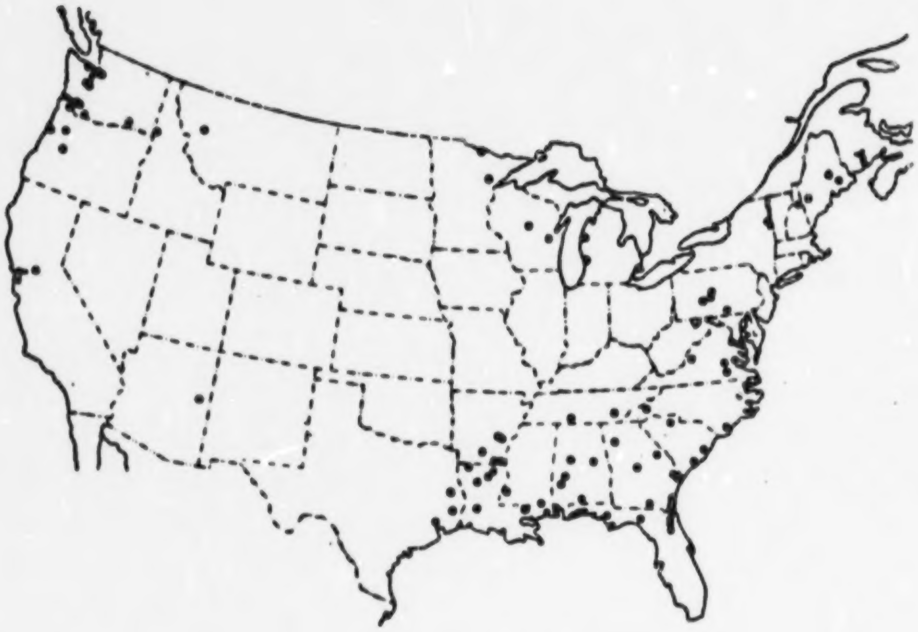


FIGURE 2

Location of Kraft Mills in the United States (1957)[141]

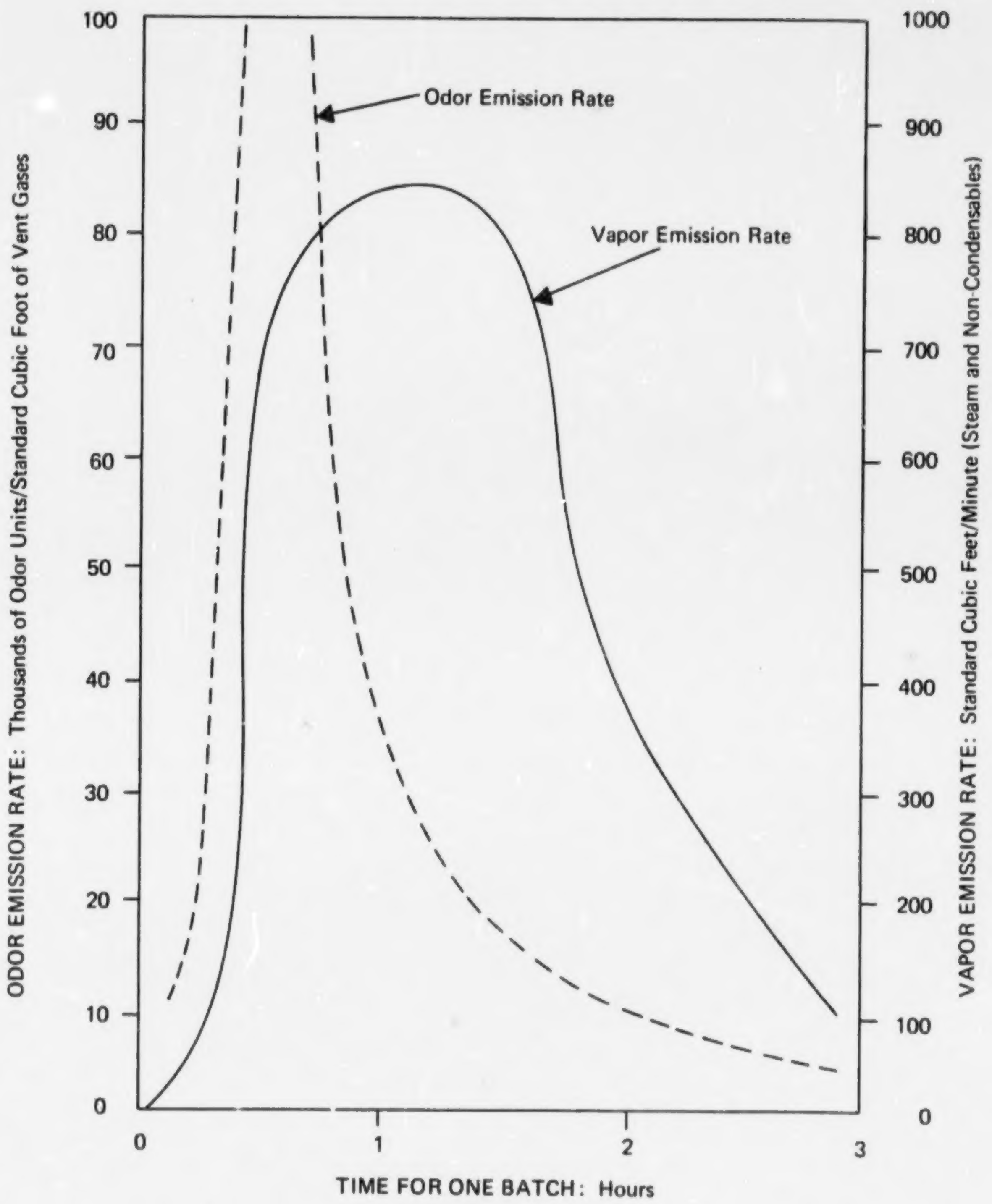


FIGURE 3

Typical Rates of Odor Emissions and of Vapor Emissions from a Batch-Type Rendering Cooker Reducing Inedible Animal Matter[179]

# APPENDIX B

## TABLE 1

## REPORTED ODOR THRESHOLD CONCENTRATIONS OF HYDROGEN SULFIDE

| ppm | μg/m$^3$ | Reference |
|---|---|---|
| 0.0011 | 1.5 | 125 |
| 0.13-1.0 | 180-1,400 | 294 |
| 0.0047 (from $Na_2S$) | 6.5 | 134 |
| 0.00047 (gas) | 0.65 | 134 |
| 0.0072 | 10 | 254 |
| 0.072 | 100 | 4 |

## TABLE 2

## RECOGNITION ODOR THRESHOLD OF ODORANTS[154]

| Odorant | µg/m³ | ppm |
|---|---|---|
| Acetaldehyde | 380[u], 130[v], 400[f] | 0.066[m], 0.21[u], 0.21<br>0.07[v], 0.07 |
| Acetephenone | 10[d] | |
| Acetic acid | | 1.0 |
| Acetone | 100[d]; 770,000[a] | 100.0, 320[a] |
| Acrolein | 820[v]; 4,500[v]; 3,500[j];<br>520[v]; 800[d]; 38,000[f] | 1.8[r,v], 0.21, 0.33[v]<br>1.5[j], 0.21[v] |
| Acrylonitrile | | 1.56[n], 21.4 |
| "Aktol" | 10,000[f] | |
| Allyl alcohol | 17,000[f] | |
| Allyl amine | 67,000[f] | 6.2[m] |
| Allyl chloride | | 0.47 |
| Allyl disulfide | 100[f]; 0.07[j] | 0.0001[j] |
| Allyl isocyanide | 4,300[f] | |
| Allyl isothiocyanate | 1,700[f] | |
| Allyl mercaptan | 500[f], 0.15[j] | 0.00005[j], 0.0015[m] |
| Allyl sulfide | 50[f] | |
| Amine dimethyl | | 0.047 |
| Amine monomethyl | | 0.021 |
| Amine trimethyl | | 0.00021 |
| Ammonia | 26[j]; 500[d]; 37,000[f] | 0.037[j]; 46.8 53[n] |
| Amyl acetate | 600[d,f] | |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Amyl alcohol | 35,000[a] | 10[a] |
| Amyl isovalerate (iso) | 800[f] | |
| Amyl mercaptan (iso) | 300[f] | |
| Amyl sulfide (iso) | 300[f] | |
| Amylene | 6,600[f] | |
| Amylenes and pentenes | | 1.8[d] |
| Anethole | 140[o] | |
| Aniline | 370[d] | 1.0 |
| Apiole | 57[j] | 0.0063[j] |
| Arsine | | 0.5[r] |
| Benzaldehyde | 3,000[f]; 430[o] | 1.3[f], 0.042[m] |
| Benzene | 180,000[a] | 3.0[c], 4.68, 60[a] |
| Benzyl chloride | 1,600[f] | 0.047 |
| Benzyl mercaptan | 190[f] | 0.0026[m] |
| Benzyl sulfide | 600[f] | 0.0021 |
| Bromacetone | 500[f] | |
| Bromacetophenone | 640[f] | |
| Bromine | | 0.047 |
| Bromoform | | 530[l] |
| i-Butanol | 120,000[a] | 40[a] |

(continued)

## TABLE 2 (Continued)

## RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| 1-Butanol | | 1.00[p] |
| n-Butanol | 33,000[a] | |
| n-Butyl acetate | 35,000[a] | 7[a] 0.6[c] |
| i-Butyl acetate | 17,000[a] | 4[a] |
| n-Butyl formate | 70,000[a] | 17[a] |
| i-Butyl mercaptan | | 0.00097[e] |
| n-Butyl mercaptan | 40,000[b]; 1,400[f] | 0.00072[e] |
| n-Butyl sulfide | 1,100[f] | |
| t-Butyl mercaptan | | 0.00009[e] |
| Butylene (beta) | 59,000[f] | |
| Butylene (gamma) | 50,000[f] | |
| Butyric acid | 1[j] | |
| Camphor | 10,000[j] | 1.6[j], 120[l] |
| Carbon disulfide | 80-500[y]; 2,300[j], 50[d]; 2,600[f] | 0.21, 0.77[j] |
| Carbon monoxide | d | |
| Carbon tetrachloride (Chlorination of $CS_2$) | | 21.4 |
| Carbon tetrachloride (Chlorination of $CH_4$) | 1,260,000[a] | 100.0, 200[a] |
| Carvone | 550[e] | |
| Chloracetophenone | 8,500[f] | |

(continued)

## TABLE 2 (Continued)

## RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Chloral | | 0.047 |
| Chlorine | 0.01[j]; 1,000[d]; 10,000[f] | 29[j], 0.314, 3.5[r] |
| Chlorobenzil | 400[d] | |
| Chlorophenol | 180[f] | |
| Chloropicrin | 7,300[f] | |
| Chloroprene | 400[d] | |
| B-Chlorvinyldichlorarsine | 14,000[f] | |
| Chromium (hexavalent) | d | |
| Citral | 300[o] | |
| Coumarine | 340[f] | |
| m-Cresol | | 0.25[p] |
| o-Cresol | | 0.26[p] |
| p-Cresol | 900[o] | |
| Creosote | | 0.031[n] |
| Crotonaldehyde | 21,000[f] | |
| Crotyl mercaptan | 29[f] | |
| Cyclohexanol | d | 160[l] |
| Cyanogen chloride | 2,500[f] | |
| Cyclohexanone | d | |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | μg/m³ | ppm |
|---|---|---|
| Cycloheptanone | | 130[l] |
| Diacetyl | 88[j] | 0.025[j] |
| Dichlordiethyl sulfide | 1,300[f] | |
| 1,2-Dichloroethane | 450,000[a]; 23,200[d] | 110[a] |
| Dichlorethylene (trans) | 4,300[f] | |
| Diethyl disulfide | | .0046 |
| Diethyl ketone | 33,000[a] | |
| Diethyl sulfide | | 0.003[k], .0059[e] |
| Diethyl trisulfide | | .00085[e] |
| Diketene | 19[d] | |
| Dimethylamine | 1,100[j] | 0.6[j] |
| Dimethylacetamide | | 46.8 |
| Dimethyl disulfide | | .0076[c] |
| Dimethyl formamide | 880[d] | 100.0 |
| Dimethyl sulfide | 51[j] | 0.004[k], .0025[e], 0.001, 0.02[j] |
| Dimethyl trisulfide | | .0014[e] |
| Dimethyl trithiocarbonate | 180[f] | |
| Dinitro-o-cresol | d | |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | µg/m³ | ppm |
|---|---|---|
| Dinyl | 80[d] | |
| Dioxane | 620,000[a] | 170[a] |
| Diphenyl chlorarsine | 300[f] | |
| Diphenyl ether (perfume grade) | 69[f] | 0.1 |
| Diphenyl cyanarsine | 300[f] | |
| Diphenyl oxide | 69[o] | |
| Diphenyl sulfide | 48[f] | 0.0047 |
| Diphenylamine chlorarsine | 2,500[f] | |
| Diphosgene | 8,800[f] | |
| Di-n-propyl sulfide | | .023[e], 0.01[k] |
| Di-i-propyl sulfide | | .0038[e] |
| Dithio-ethylene glycol | 1,600[f] | |
| Epichlorohydrin | 300[d] | |
| Ethanol (synthetic) | 93[a] | 10.0, 50[a] |
| Ethyl acetate | 600[d]; 180,000[a] | 50[a] |
| Ethyl acrylate | | 0.00047 |
| Ethyl dichlorarsine | 1,000[f] | |
| Ethyl glycol | 90,000[a] | 25[a] |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Ethyl isothiocyanate | 38,000[f] | |
| Ethyl mercaptan | 30,000[b]; 190[f]; 0.04[j] | 0.002[k], 0.0033[k], 0.001, .0004[e], 0.000016[j] |
| Ethyl methyl disulfide | | .014[e] |
| Ethyl selenide | 62[f], 0.35[j] | 0.000062[j] |
| Ethyl seleno mercaptan | 1.8[f], 0.008[j] | 0.0000018[j], 0.00030[m] |
| Ethyl sulfide | 250[f], 0.92[j] | 0.00025[j] |
| Ethylene dichloride | 25,000[f] | |
| Ethylene oxide | 1,500[d] | |
| Eugenol | 3,900[o] | |
| Fluorides | d | |
| Formaldehyde | 1,200[u]; 60[t]; 70[d]; 72-108[s] | 0.06-0.09[s], 1.0, 1.0[u], 0.4-6.6[s,k], 0.05[t] |
| Furfural | 1,000[d] | |
| Gasoline | | 10.0[d] |
| Gasoline (thermal cracked) | | 3.120[n] |
| Gasoline-shale | 300[bb] | 0.3[d] |
| Heptane | 930,000[a] | 220[a] |
| n-Heptyl alcohol | | 20[l] |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Hexamethylenediamine | d | |
| Hydrochloric acid gas | | 10.0 |
| Hydrogen chloride | 100[d] | |
| Hydrogen cyanide | 1,000[f] | 1[r] |
| Hydrogen fluoride | 30[d] | |
| Hydrogen selenide | 1,000[j] | 0.3[j] |
| Hydrogen sulfide | 14-30[aa]; 12-30[z]; 1.5[j]; 10[d]; 1,100[f] | .01[y], 0.00110[j], 0.13-1.0[n] |
| Hydrogen sulfide (from $Na_2S$) | | 0.0047 |
| Hydrogen sulfide gas | | 0.00047 |
| 15-Hydroxy Pentadecanoic acid lactone | | 270[l] |
| Iodoform | 6.1[j] | 0.00037[j] |
| Ionone | 0.0046[j] | 0.000000059[j] |
| Isopropyl benzene | 60[d] | 0.029[d] |
| Isoamyl isovalerate | 800[o] | |
| Isoborhylacetate | 440[o] | |
| Isopropyl hydroperoxide | 30[d] | |
| Lead | d | |

(continued)

## TABLE 2 (Continued)

## RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Lead sulfide | d | |
| Linalyl acetate | | $10^{l}$ |
| Maleic anhydride | $1,000^{d}$ | |
| Mercury | d | |
| Methanol | $7,800,000^{a}$; $4,300^{d}$ | 100.0; $5,900^{a}$ |
| Methyl acetate | $500^{d}$; $550,000^{a}$ | $200^{a}$ |
| Methyl anthranilate | $370^{f}$ | |
| Methyl chloride | | (Above 10 ppm) |
| Methyl dichlorarsine | $800^{f}$ | |
| Methyl ethyl ketone | $80,000^{a}$ | 10.0, $25^{a}$ |
| Methyl formate | $5,000,000^{a}$ | $2,000^{a}$ |
| Methyl glycol | $190,000^{a}$ | $60^{a}$ |
| Methyl isobutyl ketone | $32,000^{a}$ | 0.47, $8^{a}$ |
| Methyl mercaptan | $1,100^{f}$; $2.2^{j}$ | $0.0011^{j}$, $0.04^{k}$, $0.041^{m}$, 0.0021, $.00099^{e}$ |
| Methyl methacrylate | | 0.21 |
| Methyl n-nonyl ketone | | $500^{k}$ |
| Methyl propyl ketone | $27,000^{a}$ | $8^{a}$ |
| Methyl salicylate | $120,000^{o}$ | |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Methyl sulfide | $1{,}100^f$ | |
| Methyl thiocyanate | 9,600 | |
| Methylene chloride | $550{,}000^a$ | $214.0$, $150^a$ |
| Mineral spirits | $150{,}000^a$ | $30^a$ |
| Monochlorobenzene | | 0.21 |
| Musk, synthetic | $0.005^j$ | $0.00000042^j$ |
| Nitrobenzene | $18.2^d$; $30{,}000^f$ | 0.0047 |
| Nitrogen dioxide | | 4.0, $1\text{-}3^x$ |
| Nitrogen oxides | d | |
| Octane | $710{,}000^a$ | $150^a$ |
| Oxidized oils | $1{,}100^f$ | |
| Ozone | $200^j$; $1{,}000^f$ | $0.02\text{-}0.05^r$, $0.02^g$, $0.005^h$, $2.0^h$, $0.5^h$, $0.012^h$, $0.01^i$, $0.1^j$ |
| Paracresol | | 0.001 |
| Paraxylene | | 0.47 |
| Perchloroethylene | | 4.68 |
| Phenol | $1{,}200^j$; $184^d$ | $4.2^p$, $15^l$, 0.047, $0.3^j$ |
| Phenyl isocyanide | $29^f$ | |
| Phenyl isothiocyanate | $2{,}400^f$ | |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Phosgene | 4.400[f] | 5.6[r], 1.0 |
| Phosphine | | 0.021 |
| Polychloroprene suspension | | 0.025[n] |
| n-Propanol | 80,000[a] | 30[a] |
| i-Propanol | 90,000[a] | 40[a] |
| Propionaldehyde | 2,000[f] | |
| n-Propyl acetate | 70,000[a] | 20[a] |
| i-Propyl acetate | 140,000[a] | 30[a] |
| n-Propyl mercaptan | 30,000[a]; 75[f]; 0.23[j] | 0.000075[j], .00075[e]. 0.02[k] |
| i-Propyl mercaptan | | .00045[e] |
| b-Propyl sulfide | 810[f] | |
| Pyridine | 40[j]; 210[d]; 3,700[f] | 0.82[p], 0.021, 0.012[j], 0.23[m] |
| Skatole | 0.0004[j]; 9,000[f] | 0.000000075[j], 0.019[m] |
| Styrene (inhibited) | | 0.1 |
| Styrene (uninhibited) | | 0.017[n], 0.047 |
| Styrol | 36[d] | |
| Sulfur dichloride | | 0.001 |
| Sulfur dioxide | 7,900[j]; 870[d] | .03-1.0[r], 0.47, 3.0[j] |

(continued)

TABLE 2 (Continued)

RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | μg/m$^3$ | ppm |
|---|---|---|
| Sulfuric acid | 600[d] | |
| Tetrachloroethylene | 320,000[a] | 50[a] |
| Tetradodecyl mercaptan | 9,000,000[b] | |
| Tetrahydrofurane | 90,000[a] | 30[a] |
| Thiocrespol | 100[f] | |
| Thiophane | | .00077[e] |
| Thiophenol | 62[f] | |
| Thiophenol mercaptan | | 0.00026[m] |
| Tolvene | | 0.25[n] |
| Tolvene (from coke) | 140,000[a] | 4.68, 40[a] |
| Tolvene (from petroleum) | | 2.14 |
| Tolvene diisocyanate | 200[d] | |
| 1,1,1-Trichloroethane | 2,100,000[a] | 400[a] |
| Trichloroethylene | 135,000[j]; 440,000[a] | 21.4, 80[a], 25[j] |
| Trimethylamine | 9,600[j] | 0.4[j] |
| Trinitro butyl xylene | 10[f] | |
| Valeric acid vapor | d | |
| Valeric acid | 2.6[j] | 0.00062[j] |
| Vanadium pentoxide | d | |

(continued)

## TABLE 2 (Continued)

## RECOGNITION ODOR THRESHOLD OF ODORANTS

| Odorant | $\mu g/m^3$ | ppm |
|---|---|---|
| Vanillin | 0.0002[j] | 0.000000032[j] |
| Vinyl acetate | 1,000[d] | |
| m-Xylene | | 1.1[p] |
| o-Xylene | | 1.8[o] |
| p-Xylene | | 0.53[p] |
| Xylene | 100,000[a] | |
| Xylol | 730[d] | |

[a] Reference 167.
[b] Reference 10.
[c] Reference 259.
[d] Reference 260.
[e] Reference 298.
[f] Reference 4.
[g] Reference 128.
[h] Reference 289.
[i] Reference 35.
[j] Reference 125.
[k] Reference 81.
[l] Reference 166.
[m] Reference 272
[n] Reference 255.
[o] Reference 93.
[p] Reference 236.
[r] Reference 294.
[s] Reference 174.
[t] Reference 264.
[u] Reference 36.
[v] Reference 137.
[w] Reference 36.
[x] Reference 209.
[y] Reference 63.
[z] Reference 87.
[aa] Reference 19.
[bb] Reference 308.

## TABLE 3

## ODOR ADDITION OR SYNERGISM IN MIXTURES[236]

| | Fraction of Odor Threshold Concentration When Odor Could Be Perceived in the Mixture | | | |
|---|---|---|---|---|
| Test | Butanol[a] | p-Cresol[a] | Pyridine[a] | Mixture Total [b] |
| 1 | 0.46 | | 0.53 | 0.99 |
| 2 | 0.37 | 0.14 | 0.42 | 0.93 |
| 3 | 0.35 | 0.40 | | 0.75 |
| 4 | 0.24 | 0.19 | 0.29 | 0.72 |
| 5 | 0.18 | 0.21 | 0.21 | 0.60 |
| 6 | 0.15 | 0.09 | 0.26 | 0.50 |
| 7 | 0.12 | 0.21 | 0.07 | 0.40 |

[a] Fraction = $\frac{\text{measured concentration}}{\text{odor threshold concentration}}$

[b] Mixture Total = $\frac{\text{total measured concentration}}{\text{additive odor threshold concentration}}$ when the odor of the mixture could be perceived.

## TABLE 4

## CROCKER-HENDERSON ODOR CLASSIFICATION STANDARDS*[170]

| | | |
|---|---|---|
| Fragrant | | |
| | 1112 | n-Butyl phthalate |
| | 2424 | Toluene |
| | 3336 | a-Chlornaphthalene |
| | 4344 | a-Naphthyl methyl ether |
| | 5645 | Cymene |
| | 6645 | Citral |
| | 7343 | Safrole |
| | 8453 | Methyl salicylate |
| Acid | | |
| | 7122 | Vanillin |
| | 7213 | Cinnamic acid |
| | 5335 | Resorcinol dimethyl ether |
| | 2424 | Toluene |
| | 5523 | Isobutyl phenylacetate |
| | 5626 | Methyl phenylacetate |
| | 5726 | Cincole |
| | 3803 | Acetic acid (20 percent solution) |
| Burnt | | |
| | 5414 | Ethyl alcohol |
| | 7423 | Phenylethyl alcohol |
| | 5335 | Resorcinol dimethyl ether |
| | 4344 | a-Naphthyl methyl ether |
| | 4355 | Veratrole |
| | 6665 | Thujone |
| | 4376 | Paracresyl acetate |
| | 7584 | Guaiacol |
| Caprylic | | |
| | ---- | No suitable standard found |
| | 7122 | Vanillin |
| | 7343 | Safrole |
| | 5624 | Phenylacetic acid |
| | 5615 | Cymene |
| | 3336 | a-Chlornaphthalene |
| | 2577 | Anisole |
| | 3518 | 2,7-Dimethyl octane |

---

*A single substance may serve for several standards. The substances included in this table have been chosen because they are reasonably reproducible in odor from lot to lot, safe to breathe in quantities required for comparison, readily available from chemical sources, and reasonably stable against changes in use or on standing.

### TABLE 5

### AMOORE CLASSIFICATION OF ODOR QUALITY[12]

| Odor | No. of Compounds |
|---|---|
| 1. Camphoraceous | 106 |
| 2. Pungent | 95 |
| 3. Ethereal | 53 |
| 4. Floral | 71 |
| 5. Pepperminty | 77 |
| 6. Musky | 69 |
| 7. Putrid | 49 |
| 8. Almond | 30 |
| 9. Aromatic | 27 |
| 10. Aniseed | 12 |
| 11. Lemon | 7 |
| 12. Cedar | 7 |
| 13. Garlic | 7 |
| 14. Rancid | 6 |
| Total | 616 |

APPENDIX B

## TABLE 6

## ODOR QUALITIES OF SELECTED ODORANTS[190]

| Compound | Formula | Odor Quality |
|---|---|---|
| | INORGANIC COMPOUNDS | |
| Ammonia | $NH_3$ | Ammoniacal |
| Antimony compounds | | Garlic |
| Arsine | $AsH_3$ | Garlic |
| Bismuth compounds | | Garlic |
| Carbon dioxide | $CO_2$ | Odorless |
| Carbon disulfide | $CS_2$ | Strong objectionable odor |
| Carbon monoxide | $CO$ | Faint, garlic |
| Chlorine monoxide | $Cl_2O$ | Chlorine |
| Chlorine peroxide | $CLO_2$ | Unpleasant |
| Cyanogen | $C_2N_2$ | Faint, peach |
| Hydrochloric acid | $HCl$ | Halogen |
| Hydrochromic acid | $HBr$ | Halogen |
| Hydrofluoric acid | $HF$ | Halogen |
| Hydrogen cyanide | $HCN$ | Bitter almonds |

(continued)

## TABLE 6 (Continued)

## ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Hydrogen peroxide | $H_2O_2$ | Odorless |
| Hydrogen persulfide | $H_2S_2$ | Pungent, irritating odor |
| Hydrogen selenide | $H_2Se$ | Garlic |
| Hydrogen sulfide | $H_2S$ | Rotten eggs |
| Hydroiodic acid | HI | Halogen |
| Hydroxylamine | $NH_2OH$ | Odorless |
| Hydrozoic acid | $N_3H$ | Penetrating, unpleasant |
| Monocloramine | $NH_2Cl$ | Penetrating |
| Nitrogen dioxide | $NO_2$ | Strong, irritating |
| Nitrous oxide | $N_2O$ | Faint, pleasant odor |
| Phosgene | $COCl_2$ | Faint, musty hay |
| Phosphine | $PH_3$ | Decayed fish |
| Phosphorus compounds | | Garlic |
| Selenium compounds | | Garlic |
| Silicon fluoride | $SiF_4$ | Pungent |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Stannic chloride | $SuCl_4$ | Pungent |
| Sulfur chloride | $S_2Cl_2$ | Pungent |
| Thiophosgene | $CSCl_2$ | Powerful fetid smell |
| Titanic chloride | $TiCl_4$ | Pungent |
| | HYDROCARBONS | |
| Methane | $CH_4$ | Odorless |
| Ethane | $C_2H_6$ | Practically odorless |
| Propane | $C_3H_8$ | Practically odorless in concentrations below inflammable limits |
| Butane | $C_4H_{10}$ | |
| Hexane | $C_6H_{14}$ | Easily noticeable |
| Heptane | $C_7H_{16}$ | Easily noticeable |
| Octane | $C_8H_{18}$ | Powerful gasoline odor |
| Nonane | $C_9H_{20}$ | Powerful gasoline odor |
| Decane | $C_{10}H_{22}$ | Powerful gasoline odor |
| Ethylene | $C_2H_4$ | Ethereal |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Acetylene | $C_2H_2$ | Garlic |
| Cyclohexane | $C_6H_{12}$ | Bland, fatty benzene |
| Cyclohexene | $C_6H_{10}$ | Pungent |
| 1,3-Cyclohexadiene | $C_6H_8$ | Strong, pungent |
| 1,4-Cyclohexadiene | $C_6H_8$ | Weak, pungent |
| Benzene | $C_6H_6$ | Odor of dry-cleaning agent |
| Naphthalene | $C_{10}H_8$ | Odor of mothballs |
| Diphenylmethane | $(C_6H_5)_2CH_2$ | Odor of geraniums when dilute; also said to resemble oranges |
| Dibenzyl | $C_6H_5CH_2CH_2CH_5$ | Fragrant |
| Limonene | $CH_2CH_2C(CH_3)CH\ CH_2CH\ C(CH_2)CH_3$ | Agreeable lemonlike odor |
| | OFFENSIVE ODORANTS | |
| Ammonia | $NH_3$ | Ammoniacal |
| Methyl amine | $CH_3NH_2$ | Fishy |
| Dimethyl amine | $(CH_3)_2NH$ | Fishy |

(continued)

## TABLE 6 (Continued)

## ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Trimethyl amine | $(CH_3)_3N$ | Fishy |
| Ethyl amine | $CH_3CH_2NH_2$ | Fishy |
| Diethyl amine | $(CH_3CH_2)_2NH$ | Fishy |
| Triethyl amine | $(CH_3CH_2)_3N$ | Fishy |
| Putrescine | $NH_2(CH_2)_4NH_2$ | Decayed flesh |
| Cadaverine | $NH_2(CH_2)_5NH_2$ | Decayed flesh |
| Hydrogen sulfide | $H_2S$ | Rotten eggs |
| Methyl mercaptan | $CH_3SH$ | Skunk |
| Ethyl mercaptan | $CH_3CH_2SH$ | Skunk |
| n-Propyl mercaptan | $CH_3CH_2CH_2SH$ | Skunk |
| n-Butyl mercaptan | $CH_3(CH_2)_3SH$ | Skunk |
| Dimethyl sulfide | $(CH_3)_2S$ | Rotten cabbage |
| Diethyl sulfide | $(CH_3CH_2)_2S$ | Rotten cabbage |
| Methyl ethyl sulfide | $CH_3SCH_2CH_3$ | Rotten cabbage |
| Dimethyl disulfide | $CH_3SSCH_3$ | Rotten cabbage |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Diethyl disulfide | $(CH_3CH_2S)_2$ | Rotten cabbage |
| | ALCOHOLS AND PHENOLS | |
| Geraniol | $(CH_3)_2C{:}CH\cdot CH_2\cdot CH_2\cdot C(CH_3){:}CH\cdot CH_2OH$ | Roses |
| Linalool | $(CH_3)_2C{:}CH\cdot CH_2\cdot CH_2\cdot C(CH_3)OH\cdot CH{:}CH_2$ | Fragrant |
| p-Cresol | $CH_3-C_6H_4-OH$ | Strong |
| o-Cresol | $CH_3-C_6H_4OH$ | Intermediate |
| m-Cresol | $CH_3-C_6H_4OH$ | Weak |
| 2-4 Xylen-1-ol | $(CH_3)_2C_6H_3OH$ | Faint |
| 2-5 Xylen-1-ol | $(CH_3)_2C_6H_3OH$ | Mild cresolic odor |
| 3-5 Xylen-1-ol | $(CH_3)_2C_6H_3OH$ | Strong cresolic odor |
| 3-4 Xylen-1-ol | $(CH_3)_2C_6H_3OH$ | Dull, musty |
| 2-6 Xylen-1-ol | $(CH_3)_2C_6H_3OH$ | Oil of wintergreen |
| Ethanol | $C_2H_5OH$ | Sweet spiritous odor |
| Nonanol | $C_9H_{19}OH$ | Strong, disagreeable |
| Cetyl alcohol | $C_{16}H_{33}OH$ | Faint, ethereal, waxy |

(continued)

## TABLE 6 (Continued)

## ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Allyl alcohol | $CH_2{:}CH\ CH_2OH$ | Irritating |
| Propargyl alcohol | $CH{=}C{\cdot}CH_2OH$ | Agreeable |
| Oleyl alcohol | $CH_3(CH_2)_7CH{:}(CH_2)_7CH_2OH$ | Faint, waxy |
| Glycol | $CH_2OH\ CH_2OH$ | Odorless |
| Glycerol | $CH_2OH{\cdot}CHOH{\cdot}CH_2OH$ | Odorless |
| Benzyl alcohol | $C_6H_5CH_2OH$ | Faint aromatic odor |
| Phenylethyl alcohol | $C_6H_5CH_2CH_2OH$ | Constituent of rose perfume |
| Cinnamyl alcohol | $C_6H_5CH{:}CH\ CH_2OH$ | Weak, pleasant hyacinth odor |
| Menthol | $(CH_2)_2CH(CH_3)CH_2CH(OH)CH\ CH(CH_3)$ | Peppermint odor |
| Terpineol | $(CH_2)_2C(CH_3)CHCH_2CH\ C(CH_3)_2OH$ | Lilac odor |
| Phenol | $C_6H_5OH$ | Carbolic, disinfectant odor |
| Xylenol | $C_6H_3(CH_3)_2OH$ | Similar, less sharp |
| Resorcinol | $1{\cdot}3{\cdot}C_6H_4(OH)_2$ | Odorless |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| | ETHERS | |
| Heptyl hexyl ether | $C_7H_{15}OC_6H_{13}$ | Odor like bluebell stalks |
| Heptyl heptyl ether | $C_7H_{15}OC_7H_{15}$ | Odor like wet wool |
| Heptyl undecyl ether | $C_7H_{15}OC_{11}H_{23}$ | Fugitive odor of fatty aldehydes |
| Heptyl phenyl ether | $C_7H_{15}OC_6H_5$ | Odor of opoponax |
| 3,7-Dimethyl-e-methoxy-oct-6-en-1-yn | | Bergamot |
| 3,7-Dimethyl-3-ethoxy-oct-6-en-1-yn | | Bergamot |
| 3,7-Dimethyl-3-amyloxy-oct-6-en-1-yn | | Jasmine |
| 3,7-Dimethyl-3-allyloxy-oct-6-en-1-yn | | Jasmine and fruity |
| 3,7-Dimethyl-3-benzyloxy-oct-6-en-1-yn | | Cinnamon |
| 3,6,7-Trimethyl-6-methoxy-oct-6-en-1-yn | | Nutmeg |
| 3,7-Dimethyl-3-propargyloxy-oct-6-en-1-yn | | Rosewood |
| 3,7,11-Trimethyl-3-methoxy-dodeca-6,10-dien-1-yn | | Lily |
| 3,7,11-Trimethyl-3-allyloxy-dodeca-6,10-dien-1-yn | | Lily, fruity |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| 3-Methyl-3-methoxy-6-cyclohexyliden-hex-1-yn | | Vetiver |
| 3-Methyl-3-allyloxy-6-cyclohexyliden-hex-1-yn | | Coriander |
| Diethyl ether | $C_2H_5OC_2H_5$ | Sweet spiritous |
| Heptyl hexyl ether | $C_7H_{15}OC_6H_{13}$ | Bluebell stalks |
| Anisole | $CH_3OC_6H_5$ | Fragrant, overpowering |
| Phenetole | $C_2H_5OC_6H_5$ | Fragrant, aromatic |
| Diphenyl ether | $C_6H_5OC_6H_5$ | Geraniums when dilute |
| | CARBOXYLIC ACIDS | |
| Formic acid | $H\cdot COOH$ | Pungent, irritating |
| Acetic acid | $CH_3\cdot COOH$ | Penetrating; vinegar when dilute |
| Butyric acid | $CH_3(CH_2)_2\cdot COOH$ | Disagreeable |
| Isobutyric acid | $(CH)_2CH\cdot COOH$ | More disagreeable |
| Palmitic acid | $C_{15}H_{31}\cdot COOH$ | Odorless |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Acrylic acid | $CH_2{:}CH \cdot COOH$ | More pungent than acetic |
| Crotonic acid | $CH_3 \cdot CH{:}CH \cdot COOH$ | Acrid, butyric |
| Oleic acid | $CH_3 \cdot (CH_2)_7 \cdot CH{:}CH \cdot (CH_2)_7 \cdot COOH$ | Odorless |
| Propiolic acid | $CH{=}C \cdot COOH$ | Acrylic |
| Lactic acid | $CH_3CHOH \cdot COOH$ | Odorless |
| Succinic acid | $COOH \cdot (CH_2)_2 \cdot COOH$ | Odorless |
| Tricarballylic acid | $COOH \cdot CH_2 \cdot CH\ COOH \cdot CH_2COOH$ | Odorless |
| Phenylacetic acid | $C_6H_5 \cdot CH_2COOH$ | Weak civet |
| Benzoic acid | $C_6H_5 \cdot COOH$ | Odorless |
| Hexahydrobenzoic acid | $C_6H_{11} \cdot COOH$ | Rancid |
|  | ESTERS |  |
| Propyl acetate | $C_3H_7 \cdot O \cdot CO \cdot CH_3$ | Like pears |
| Amyl acetate | $C_3H_{11}O \cdot CO \cdot CH_3$ | Like Jargonelle pears |
| Isoamyl acetate | $(CH_3)_2CH \cdot CH_2 \cdot CH_2 \cdot O \cdot CO \cdot CH_3$ | Like pears |

(continued)

## TABLE 6 (Continued)

## ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Ethyl butyrate | $C_2H_5 \cdot O \cdot CO \cdot C_3H_7$ | Like pineapples |
| Isoamyl isovalerate | $(CH_3)_2CH \cdot C_2H_4 \cdot O \cdot CO \cdot C_4H_9$ | Like apples |
| Heptyl formate | $C_7H_{15} \cdot O \cdot CO \cdot H$ | Fruity |
| Heptyl acetate | $C_7H_{15} \cdot O \cdot CO \cdot CH_3$ | Fruity |
| Heptyl isobutyrate | $C_7H_{15} \cdot O \cdot CO \cdot C_3H_7$ | Cyclamen-camomile |
| Heptyl caproate | $C_7H_{15} \cdot O \cdot CO \cdot C_5H_{11}$ | Bruised green leaves |
| Heptyl undecylate | $C_7H_{15} \cdot O \cdot CO \cdot C_{10}H_{21}$ | Smoke, ink |
| Heptyl salicylate | $C_7H_{15} \cdot O \cdot CO \cdot C_6H_4OH$ | Steel |
| Heptyl geranate | $C_7H_{15} \cdot O \cdot CO \cdot C_9H_{15}$ | Hawthorn, mimosa |
| Methyl acetate | $CH_3OCO\ CH_3$ | Fragrant |
| Ethyl acetate | $C_2H_5OCO\ CH_3$ | Fragrant |
| Octyl acetate | $C_8H_{17}OCO\ CH_3$ | Orange |
| Diethyl adipate | $C_2H_5OCO\ (CH_2)_4 \cdot OCOC_2H_5$ | Fruity |
| Ethyl hydrogen adipate | $C_2H_5OCO\ (CH_2)_4COOH$ | Fruity |

(continued)

APPENDIX B

## TABLE 6 (Continued)

## ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Triethyl citrate | $(C_2H_5OCOCH_2)_2C(OH)COOC_2H_5$ | Fruity |
| Melissyl palmitate | $C_{30}H_{61}OCO\ C_{15}H_{31}$ | Odorless |
| Benzyl acetate | $C_4H_5CH_2OCO\ CH_3$ | Jasmine |
| Methyl salicylate | $CH_3OCO\ C_6H_4OH$ | Oil of wintergreen |
| Amyl salicylate | $C_5H_{11}OCO\ C_6H_4OH$ | Clover |
|  | ALDEHYDES |  |
| Alpha-methyl cinnamaldehyde | $C_6H_5CH{:}C(CH_3)CHO$ | Gentle cinnamon, grassy |
| Alpha-ethyl cinnamaldehyde | $C_6H_5CH{:}C(C_2H_5)CHO$ | Mild cinnamon, nasturtium |
| Alpha-n-propyl cinnamaldehyde | $C_6H_5CH{:}C(C_3H_7)CHO$ | Sweet, faintly animal |
| Alpha-n-butyl cinnamaldehyde | $C_6H_5CH{:}C(C_4H_9)CHO$ | Strong, fatty, green |
| Alpha-n-amyl cinnamaldehyde | $C_6H_5CH{:}C(C_5H_{11})CHO$ | Very powerful, jasmine |
| Alpha-n-hexyl cinnamaldehyde | $C_6H_5CH{:}C(C_6H_{13})CHO$ | Less powerful, jasmine, green |
| Alpha-n-heptyl cinnamaldehyde | $C_6H_5CH{:}C(C_7H_{15})CHO$ | Sweet |
| Alpha-n-octyl cinnamaldehyde | $C_6H_5CH{:}C(C_8H_{17})CHO$ | Faint, almond, no longer green |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Alpha-n-decyl cinnamaldehyde | | Very faint |
| Formaldehyde | $H \cdot CHO$ | Pungent formalin |
| Paraformaldehyde | $(CH_2O)_n$ | Mild formalin |
| Acetalehyde | $CH_3CHO$ | Pungent |
| Acrolein | $CH_2:CH\ CHO$ | Irritating, snuffed candle |
| Propiolaldehyde | $CH\equiv C \cdot CHO$ | Irritating |
| Stearaldehyde | $C_{17}H_{35}CHO$ | Faint waxy |
| Geranial (citral) | $(CH_3)_2C:CH\ C_2H_4C(CH_3):CH \cdot CHO$ | Lemon |
| Glycollic aldehyde | $CH_2OH \cdot CHO$ | Odorless |
| Benzaldehyde | $C_6H_5CHO$ | Bitter almonds |
| Cinnamic aldehyde | $C_6H_5CH:CH\ CHO$ | Cinnamon |
| Piperonal | $CH_2O_2C_6H_3CHO$ | Heliotrope |
| Phenylethyl aldehyde | $C_6H_5CH_2CHO$ | Hyacinth |
| Salicylaldehyde | $o\text{-}HO\ C_6H_4CHO$ | Spirea |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Aubepine | p-$CH_3O$ $C_6H_4CHO$ | Hawthorn |
| Vanillin | $CHO\text{-}C_6H_3\text{-}OH\ OCH_3$ | Vanilla |
| Furfural | $C_4H_3O \cdot CHO$ | New bread |
| Alpha-Amyl cinnamic (jasmine) aldehyde | $C_6H_5\text{-}CH{:}C(C_5H_{11})CHO$ | Jasmine |
|  | **ACETALS** |  |
| Alpha, beta-dihydroxypropane | $CH_2OH \cdot CHOH \cdot CH_3$ | The acetal smells of fresh roses |
| Alpha, beta-dihydroxybutane | $CH_2OH \cdot CHOH \cdot C_2H_5$ | The acetal smells of hyacinths |
| Alpha, gamma-dihydroxybutane | $CH_2OH \cdot CH_2 \cdot CHOH \cdot CH_3$ | The acetal smells of hyacinths |
| 2:4 dihydroxy-4-methylpentane | $CH_3 \cdot CHOH \cdot CH_2C(OH)CH_3 \cdot CH_3$ | Mignonette |
|  | **HALIDES** |  |
| Methyl chloride | $CH_3Cl$ | Ethereal |
| Methylene chloride | $CH_2Cl_2$ | Ethereal |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Chloroform | $CHCl_3$ | Sweet, ethereal |
| Iodoform | $CHI_3$ | Saffron |
| Chlorobenzene | $C_6H_5 \cdot Cl$ | Mild |
| p-Dichlorbenzene | $C_6H_4{-}Cl_2$ | Camphor, naphthalene |
| Benzyl chloride | $C_6H_5 \cdot CH_2Cl$ | Stupefying |
| Hexachlorethane | $C_2Cl_6$ | Camphoraceous |
|  | AMINES |  |
| Methylamine | $CH_3 \cdot NH_2$ | Ammonia, boiled lobsters |
| Trimethylamine | $(CH_3)_3 \cdot N$ | Herring brine |
| Triethanolamine | $(C_2H_4OH)_3N$ | Oily, slightly fishy |
| Tetraethylammonium hydroxide | $(C_2H_5)_4N \cdot OH$ | Odorless |
| Aminovaleric acid | $NH_2 \cdot (CH_2)_4COOH$ | Odorless |
| Cadaverine | $NH_2 \cdot (CH_2)_5NH_2$ | Decaying flesh |
| Benzylamine | $C_6H_5 \cdot CH_2 \cdot NH_2$ | Ammoniacal |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Aniline | $C_6H_5 \cdot NH_2$ | Gas, lime |
| Diphenylamine | $(C_6H_5)_2NH$ | Floral |
| Anthranilic acid | $C_6H_4NH_2\text{-}COOH$ | Odorless |
| Methyl anthranilate | $C_6H_4NH_2\text{- }COOCH_3$ | Orange blossom, jasmine |
| | NITROGEN COMPOUNDS | |
| Methyl nitrate | $CH_3 \cdot O \cdot NO_2$ | Pleasant ester |
| Methyl nitrite | $CH_3 \cdot O \cdot NO$ | Powerful, oppressive |
| Nitromethane | $CH_3 \cdot NO_2$ | Pleasant |
| Beta-Nitrohexane | $CH_3 \cdot (CH_2)_3 \cdot CH(NO_2) \cdot CH_3$ | Aniseed |
| Nitrobenzene | $C_6H_5 \cdot NO_2$ | Coarse, bitter almonds |
| Acetamide | $CH_3 \cdot CO \cdot NH_2$ | "Mice" usually, odorless if pure |
| Methyl cyanide | $CH_3 \cdot CN$ | Agreeable, reminiscent of prussic acid |
| Sebacic dinitrile | $CN(CH_2)_8CN$ | Unpleasant, nutty |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Ethyl carbylamine | $C_2H_5N:C$ | Offensive, nauseating |
| Phenylhydrazine | $C_6H_5\cdot NH\cdot NH_2$ | Pleasant, aromatic |
| Diazomethane | $CH_2N_2$ | Odorless |
| Tetraethyl tetrazine | $(C_2H_5)_2N\cdot N:N\cdot N(C_2H_5)_2$ | Alliaceous |
|  | SULFUR COMPOUNDS |  |
| Allyl sulfide | $(CH_2:CH\cdot CH_2)_2S$ | Garlic |
| Allyl isothiocyanate | $CH_2:CH\cdot CH_2N:CS$ | Mustard |
| Ethyl isothiocyanate | $C_2H_5\cdot N:CS$ | Mustard |
| Ethyl thiocyanate | $C_2H_5\cdot S\cdot C:N$ | Onions |
| Ethyl sulfite | $(C_2H_5O)_2\cdot SO$ | Peppermint |
| Diethyl sulfate | $(C_2H_5O)_2\cdot SO_2$ | Heavy, sweet, ethereal |
| Amyl mercaptan | $C_5H_{11}\cdot SH$ | Powerful, unpleasant |
| Mustard gas | $(ClCH_2\cdot CH_2)_2S$ | Horseradish |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Phenyl thiocarbimide | $C_6H_5N:CS$ | Mustard |
| p-Thiocarbimide benzaldehyde | $CHO-C_6H_4-N:CS$ | Cherry pie |
| m-Tolyl thiocarbimide | $CH_3-C_6H_4NCS$ | Pungent |
| p-Tolyl thiocarbimide | $CH_3-C_6H_4-N:CS$ | Sweet anise |
| | HETEROCYCLIC COMPOUNDS | |
| Ethylene oxide | $(CH_2)_2O$ | Sweet, ethereal |
| Ethylene imine | $(CH_2)_2NH$ | Ammoniacal |
| Succinic anhydride | $(CH_2CO)_2O$ | Suffocating |
| Butyrolactone | $CH_2CH_2CH_2OCO$ | Faintly aromatic |
| Furfular | $C_4H_3OCHO$ | New bread |
| Thiophen | $C_4H_4S$ | Faint, neutral |
| Pyrrol | $C_4H_4NH$ | Chloroform |
| Pyridine | $C_5H_5N$ | Rank, unpleasant |

(continued)

## TABLE 6 (Continued)

## ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Quinoline | $C_9H_7N$ | Aromatic, aniseed |
| Piperidine | $C_5H_{10}NH$ | Ammoniacal, pungent |
| Dioxane | $C_4H_8O_2$ | Faint, sweet, ethereal |
| Morpholine | $C_4H_8ONH$ | Faint, ammoniacal |
| Piperazine | $C_4H_8(NH)_2$ | Bitter odor like dandelions, slightly ammoniacal |
| Alpha-Phenylpropyl pyridine | $C_6H_5(CH_2)_3-C_6H_5N$ | Roses |
| Gamma-Propyl pyridine | $C_3H_7C_5H_5N$ | Violets |
| Indole | $C_8H_6NH$ | Alpha-Naphthylamine when concentrated, but jasmine when dilute |
| Skatole | $C_8H_5NH(CH_3)$ | Fecal |
| Coniine | $C_3H_7C_5H_7NH$ | Stupefying |
| Nicotine | $C_5H_4NC_4H_7NCH_2$ | Rank, tobacco |
| Thiazole | $C_3H_2NS$ | Pyridine |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Benzothiazole | $C_6H_4NSCH$ | Quinoline |
| 2-Phenylbenzothiazole | $C_6H_4NSC \cdot C_6H_5$ | Tea rose |
| Benzoxazole | $C_6H_4NOCH$ | Tobacco |
| Pyridazine | $C_4H_4N_2$ | Pyridine |
| | MACROCYCLIC COMPOUNDS | |
| Compounds with | 9-12 atom rings | Camphor or mint |
| " " | 13 atom rings | Woody or cedar-like |
| " " | 14-15-16 atom rings | Musk |
| " " | 17-18 atom rings | Civet |
| " " | More than 18-19 atom rings | Odor practically disappears |
| Decamethylene oxalate (14-atom ring) | $(CH_2)_{10}O_2(CO)_2$ | Fresh, musk-like |
| Undecamethylene oxalate (15-atom ring) | $(CH_2)_{11}O_2(CO)_2$ | Musk odor |

(continued)

TABLE 6 (Continued)

ODOR QUALITIES OF SELECTED ODORANTS

| Compound | Formula | Odor Quality |
|---|---|---|
| Decamethylene malonate (15-atom ring) | $(CH_2)_{10}O_2(CO)_2CH_2$ | Faint musk |
| Ethylene sebacate (14-atom ring) | $(CH_2)_{10}O_2(CO)_2$ | Musk-like |
| Ethylene undecanedioate (15-atom ring) | $(CH_2)_{11}O_2(CO)_2$ | Musk-like |
| Tetraethylene carbonate (14-atom ring) | $(CH_2)_8O_5CO$ | Fresh, faint. musk-like |

## TABLE 7

## PUBLIC OPINION SURVEYS RELATING ODORS TO AIR POLLUTION

| | | Persons Responding to Survey | Persons Annoyed by Odors[a] | |
|---|---|---|---|---|
| Location | Year | Number | Number | Percent |
| Nashville, Tenn.[254] | 1959 | 2,835 | 742 | 26.2 |
| Clarkston, Wash.[172] | 1962 | 104 | 95 | 91 |
| Moerrum, Sweden[43] | 1963 | 394 | 351 | 89 |
| Terre Haute, Ind.[1] | 1964 | 20[b] | 19 | 95 |
| St. Louis, Mo.[131,221] | 1965 | 400 | 214 | 53.5 |
| St. Louis, Mo.[131,221] | 1965 | 600 | 269 | 44.8 |
| Steubenville, Ohio[124] | 1967 | 936 | 288 | 30.8 |

[a] These people described air pollution in their location as "bad smells."

[b] These people complained of air pollution with all but one mentioning odors.

## TABLE 8

## COMPLAINTS RELATING ODORS TO PROPERTY DAMAGE AND HEALTH IN TERRE HAUTE, IND.[1]

| | Number of Complaints | | |
|---|---|---|---|
| Date | Property/odor | Health/odor | Total |
| May 20, 1964 | 1 | 15 | 16 |
| May 21, 1964 | 1 | 4 | 5 |
| May 24, 1964 | 14 | 14 | 28 |
| May 26, 1964 | 6 | 0 | 6 |
| May 27, 1964 | 4 | 0 | 4 |
| June 3, 1964 | 14 | 8 | 22 |

## TABLE 9

## ODORS BY TIME OF DAY IN THE ST. LOUIS METROPOLITAN AREA[131]

(November 18 to December 1, 1963)

| Area | 7 a.m. | 2 p.m. | 8 p.m. | 10 p.m. | 12 M |
|---|---|---|---|---|---|
| St. Louis | | | | | |
| Positive observations | 126 | 136 | 192 | 176 | 157 |
| Total observations | 483 | 494 | 490 | 491 | 488 |
| % positive | 26.1 | 27.5 | 39.2 | 35.8 | 32.2 |
| St. Louis County | | | | | |
| Positive observations | 66 | 85 | 119 | 106 | 74 |
| Total observations | 371 | 370 | 372 | 360 | 311 |
| % positive | 17.8 | 23.0 | 32.0 | 29.4 | 23.8 |
| Illinois | | | | | |
| Positive observations | 43 | 39 | 54 | 56 | 56 |
| Total observations | 164 | 161 | 162 | 161 | 144 |
| % positive | 26.2 | 24.2 | 33.3 | 34.8 | 38.9 |
| Metropolitan Area | | | | | |
| Positive observations | 235 | 260 | 365 | 338 | 287 |
| Total observations | 1,018 | 1,025 | 1,024 | 1,012 | 943 |
| % positive | 23.1 | 25.4 | 35.6 | 33.4 | 30.4 |

APPENDIX B

## TABLE 10

## EFFECT OF THE DAY OF THE WEEK ON ODOR NUISANCE OCCURRENCES[118]

| Day of Week* | Number of Complaints | Number of Nuisance Occurrences |
|---|---|---|
| Sunday | 19 | 7 |
| Monday | 15 | 11 |
| Tuesday | 8 | 6 |
| Wednesday | 10 | 7 |
| Thursday | 17 | 10 |
| Friday | 34 | 11 |
| Saturday | 41 | 18 |

*During the middle of the week fewer occurrences and complaints happened. Saturday is the day of most frequent complaints and most numerous odor occurrences.

## TABLE 11

## EFFECT OF THE TIME OF DAY ON ODOR NUISANCE OCCURRENCES[118]

| Time of Day* | Number of Complaints | Number of Nuisance Occurrences |
|---|---|---|
| 0000 to 0600 | 12 | 9 |
| 0600 to 1200 | 29 | 23 |
| 1200 to 1800 | 44 | 24 |
| 1800 to 2400 | 53 | 32 |

*Only 8.7 percent of complaints and only 10 percent of the odor occurrences came during the first quarter of the day.

## TABLE 12

## EFFECT OF TEMPERATURE ON ODOR NUISANCE OCCURRENCES[118]

| Temperature Range* | No. of Complaints During 1958 & 1959 | No. of Hours at Temperature | Ratio: No. Hours/ No. Complaints |
|---|---|---|---|
| 0 to 44 | 0 | 6,184 | ∞ |
| 45 to 49 | 2 | 1,262 | 631 |
| 50 to 54 | 3 | 1,121 | 374 |
| 55 to 59 | 4 | 1,118 | 280 |
| 60 to 64 | 5 | 1,493 | 299 |
| 65 to 69 | 26 | 1,795 | 69 |
| 70 to 74 | 33 | 1,957 | 59 |
| 75 to 79 | 34 | 1,228 | 36 |
| 80 to 84 | 13 | 817 | 63 |
| 85 to 89 | 10 | 472 | 47 |
| 90 to 94 | 4 | 73 | 18 |
| 95 to 100 | 0 | 0 | - |

*The critical temperatures for these odor nuisances are above 65°F. Higher temperatures result in more frequent complaints and nuisances.

## TABLE 13

## EFFECT OF ATMOSPHERIC PRESSURE ON ODOR NUISANCE OCCURRENCES[118]

| Pressure Range* (Inches Hg) | No. of Complaints During 1958 & 1959 | No. of Hours at Pressure | Ratio: No. Hours/ No. Complaints |
|---|---|---|---|
| 0 to 28.84 | 1 | 1,234 | 1,234 |
| 28.85 to 28.89 | 6 | 790 | 132 |
| 28.90 to 28.94 | 21 | 1,424 | 68 |
| 28.95 to 28.99 | 9 | 1,714 | 190 |
| 29.00 to 29.04 | 18 | 2,032 | 113 |
| 29.05 to 29.09 | 25 | 2,260 | 90 |
| 29.10 to 29.14 | 18 | 2,090 | 116 |
| 29.15 to 29.19 | 15 | 1,770 | 118 |
| 29.20 to 29.24 | 9 | 1,720 | 191 |
| 29.25 to 29.29 | 5 | 844 | 170 |
| 29.30 | 4 | 1,622 | 406 |

*Very few complaints were received when the atmospheric pressure was below 28.84 inches Hg.

### TABLE 14

### EFFECT OF RELATIVE HUMIDITY ON ODOR NUISANCE OCCURRENCES[118]

| Relative Humidity Range* | No. of Complaints During 1958 & 1959 | No. of Hours at R.H. | Ratio: No. Hours/ No. Complaints |
|---|---|---|---|
| 0 to 30 | 0 | 453 | ∞ |
| 30 to 49 | 27 | 2,974 | 110 |
| 50 to 69 | 47 | 5,186 | 110 |
| 70 to 79 | 24 | 3,184 | 132 |
| 80 to 89 | 18 | 3,007 | 167 |
| 90 to 100 | 18 | 2,698 | 150 |

*Hours of low relative humidity (R.H.) have more frequent complaints per hour.

### TABLE 15

### EFFECT OF WIND VELOCITY ON ODOR NUISANCE OCCURRENCES[118]

| Range Wind Velocity* (mph) | No. of Complaints During 1958 & 1959 | No. of Hours at Velocity | Ratio: No. Hours/ No. Complaints |
|---|---|---|---|
| 0 to 4 | 25 | 3,584 | 143 |
| 5 to 14 | 95 | 11,105 | 117 |
| 15 to 24 | 17 | 2,740 | 161 |
| 25 to ∞ | 0 | 91 | ∞ |

*Wind velocity had no effect on the number of hours per complaint.

## TABLE 16

## EFFECT OF CHANGING TEMPERATURE, PRESSURE, AND RELATIVE HUMIDITY ON ODOR NUISANCE OCCURRENCES[118]

| Type of Change* | Temperature |  | Pressure |  | Relative Humidity |  |
|---|---|---|---|---|---|---|
|  | No. of Complaints | % of Total | No. of Complaints | % of Total | No. of Complaints | % of Total |
| Increasing | 34 | 26 | 64 | 49 | 69 | 52 |
| Static | 19 | 14 | 37 | 28 | 15 | 11 |
| Decreasing | 79 | 60 | 30 | 23 | 48 | 37 |

*On a percentage basis, decreasing temperature, increasing pressure, and increasing relative humidity cause more frequent complaints to be received.

## TABLE 17

## EFFECT OF TIME OF YEAR ON ODOR NUISANCE OCCURRENCES[118]

| Month | Number of Complaints | Number of Nuisance Occurrences* |
|---|---|---|
| January | 0 | 0 |
| February | 0 | 0 |
| March | 1 | 1 |
| April | 6 | 4 |
| May | 9 | 4 |
| June | 14 | 9 |
| July | 28 | 16 |
| August | 44 | 18 |
| September | 34 | 18 |
| October | 2 | 2 |
| November | 1 | 1 |
| December | 0 | 0 |

*The number of nuisance occurrences refers to the number of different days on which complaints occurred. Note that 86 percent of the complaints and 84 percent of the occurrences happened during the months of June, July, August, and September.

TABLE 18

THEORIES OF OLFACTION[195,234]

| Author | Date | General Class | Salient Features |
|---|---|---|---|
| Ogle[203] | 1870 | Vibrational | Vibrations affected nasal pigment, which gave out heat which excited the olfactory cells |
| Woker[304] | 1906 | Chemical | Unsaturation main cause of odor, but not essential if substance very volatile |
| Fabre[77] | 1911 | Vibrational | Limited to insects. Not known by man. Human olfaction due to material particles |
| Marchand[163] | 1915 | Chemical | Unsaturation (including carbonyl bonds). Having two points of unsaturation reduces odor |
| Henning[105] | 1916 | Chemical | Osmophore groups are important, but their relative position determines the type of odor |
| Heyninx[107] | 1917 | Vibrational | Vibrations causing absorption in the ultra-violet band also cause odor |
| Backman[18] | 1917 | Chemical | Water solubility and lipoid solubility essential |
| Teudt[278] | 1919 | Vibrational | Electronic vibrations of sensory nerves increased by reasonance with similar vibrations of odorants |
| Durrans[67] | 1920 | Chemical | Residual affinity. Addition reaction on the olfactory epithelium |
| Heller[103] | 1920 | Chemical | Direct chemical action on nerve-ending |
| Ruzicka[241] | 1920 | Chemical | Osmophore and osmoceptor |
| Tschirch[283] | 1921 | Chemical | Substance must be soluble in air. Loose compound formed with plasma of the olfactory cell |

(continued)

TABLE 18 (Continued)

THEORIES OF OLFACTION[195,234]

| Author | Date | General Class | Salient Features |
|---|---|---|---|
| Zwaardemaker[313] | 1922 | Chemical-vibrational | Odorous substances possess odoriphores, are volatile, have lower surface tension, and are lipoid soluble. Odoriphore depends on vibrations in molecule |
| Ungerer and Stoddard[287] | 1922 | Vibrational | Intramolecular vibrations within definite frequency range. Unsaturation helpful. Interference and resonance effects |
| Delange[57] | 1922 | Chemical | Unsaturation |
| Missenden[181] | 1926 | Chemical | Intensity depends on number of molecules making contact with nose. Quality depends on nature of reaction between odorous molecules and lipoid tissues |
| Nicol[200] | 1926 | | Function of sinuses |
| Pirrone[215] | 1929 | Chemical | Two smophore groups; one determines type of odor, the other the variety |
| Niccolini[199] | 1933 | Chemical | Volatility. Solubility in nasal mucosa. Oxidizability |
| Krisch[149] | 1934 | Vibrational | Insects |
| Muller[194] | 1936 | Physical | Odorous substances are dipolar. Irritate the molecular fields of the osmoceptor in nose |
| Dyson[70] | 1937 | Vibrational | Volatility. Lipoid solubility Raman shift between 1,400 and 3,500 $cm^{-1}$ |
| Beck and Miles[23] | 1947 | Vibrational | Infra-red radiation from receptors absorbed by odorants |
| McCord and Witheridge[170] | 1949 | Electro-chemical | Change in bonding angle of odorant molecules on solution in mucosa |

(continued)

TABLE 18 (Continued)

THEORIES OF OLFACTION[195,234]

| Author | Date | General Class | Salient Features |
|---|---|---|---|
| Baradi and Bourne[20] | 1951 | Enzyme | Inhibition of enzyme action by odorants |
| Hainer[99] | 1953 | Information | 30 levels of intensity; 24 kinds of primary odor |
| Wright[305] | 1954 | Vibrational | Raman shift of frequency lower than 800-1,000 $cm^{-1}$ |
| Davies[52] | 1954 | Physico-chemical | Puncturing of olfactory cell membrane and exchange of $Na^+$ and $K^+$ |
| Moncrieff[188] | 1961 | Physical | Volatility, adsorbability, and customary absence from olfactory region |
| Amoore[12] | 1962 | Stereo-chemical | Whole-molecule theory. Developed size and shape of each receptor site |
| Moncrieff[190] | 1967 | Stereo-chemical | Whole-molecule theory. Extended 1961 theory |

### TABLE 19

### MOST FREQUENTLY REPORTED ODOR SOURCES[143]

| Source of Odor | Number Reported |
|---|---|
| Animal odors | |
| Meat packing and rendering plants | 12 |
| Fish oil odors from manufacturing plants | 5 |
| Poultry ranches and processing | 4 |
| Odors from combustion processes | |
| Gasoline and diesel engine exhaust | 10 |
| Coke-oven and coal-gas odors (steel mills) | 8 |
| Poorly adjusted heating systems | 3 |
| Odors from food processing | |
| Coffee roasting plants | 8 |
| Restaurants | 4 |
| Bakeries | 3 |
| Paint and related industries | |
| Manufacturing of paint, lacquer, and varnish | 8 |
| Paint spraying | 4 |
| Commerical solvents | 3 |
| General chemical odors | |
| Hydrogen sulfide | 7 |
| Sulfur dioxide | 4 |
| Ammonia | 3 |
| General industrial odors | |
| Burning rubber from smelting and debonding | 5 |
| Odors from dry-cleaning shops | 5 |
| Fertilizer plants | 4 |
| Asphalt odors (roofing and street paving) | 4 |
| Asphalt odors (manufacturing) | 3 |
| Plastic manufacturing | 3 |
| Foundry odors | |
| Core-oven odors | 4 |
| Heat treating, oil quenching, and pickling | 3 |
| Smelting | 2 |
| Odors from combustion of waste | |
| Home incinerators and backyard trash fires | 4 |
| City incinerators burning garbage | 3 |
| Open-dump fires | 2 |

(continued)

## TABLE 19 (Continued)

## MOST FREQUENTLY REPORTED ODOR SOURCES[143]

| Source of Odor | Number Reported |
|---|---|
| Refinery odors | |
| Mercaptans | 3 |
| Crude oil and gasoline | 3 |
| Sulfur | 1 |
| Odors from decomposition of waste | |
| Putrefaction and oxidation (organic acids*) | 3 |
| Organic nitrogen compounds (decomposition of protein*) | 2 |
| Decomposition of lignite (plant cells) | 1 |
| Sewage odors | |
| City sewers carrying industrial waste | 3 |
| Sewage treatment plants | 2 |

*Probably related to meat processing plants.

APPENDIX B

## TABLE 20

## NATURE OF AIR CONTAMINANTS EMANATING FROM VARIOUS TYPES OF SOURCES[108]

| Source | Communities Over 5,000 Population[a] | | | | | Communities under 5,000 Population | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | | | | Total | | | | |
| | No. | % | Smoke | Odors | Other | No. | % | Smoke | Odors | Other |
| All sources | 409 | 100 | 258 | 103 | 48 | 167 | 100 | 99 | 40 | 28 |
| Industrial (total)[b] | 123 | 30 | 49 | 26 | 48 | 100 | 60 | 49 | 23 | 28 |
| Nonindustrial (total) | 286 | 70 | 209 | 77 | 0 | 67 | 40 | 50 | 17 | 0 |
| Apartment houses | 28 | 10 | 21 | 7 | | 5 | 7 | 3 | 2 | |
| Office buildings | 15 | 5 | 15 | | | 2 | 3 | 1 | 1 | |
| Stores | 10 | 3 | 8 | 2 | | 1 | 2 | 1 | | |
| Bakeries | 9 | 3 | 6 | 3 | | | | | | |
| Laundries | 21 | 7 | 18 | 3 | | 1 | 2 | 1 | | |
| Schools | 18 | 6 | 18 | | | 7 | 10 | 7 | | |
| Hospitals | 12 | 4 | 12 | | | 1 | 2 | 1 | | |
| Hotels | 11 | 4 | 10 | 1 | | 1 | 2 | 1 | | |
| Theaters | 9 | 3 | 7 | 2 | | 1 | 2 | 1 | | |
| Public buildings | 18 | 6 | 18 | | | 4 | 6 | 4 | | |
| Incinerators | 33 | 12 | 16 | 17 | | 3 | 4 | 2 | 1 | |
| Railroads | 16 | 6 | 13 | 3 | | 4 | 6 | 4 | | |
| Dumps | 60 | 21 | 36 | 24 | | 32 | 48 | 21 | 11 | |
| Auto and bus exhaust | 16 | 6 | 5 | 11 | | 3 | 4 | 2 | 1 | |
| Other | 10 | 3 | 6 | 4 | | 2 | 3 | 1 | 1 | |

[a] Surveys did not include New York City.

[b] No breakdown is available on types of industrial establishments.

## TABLE 21

## ODOR CONCENTRATION MEASURED IN VARIOUS PLANTS[26]

| Application | Exhaust Flow (scfm) | Average* Odor Concentration (odor units/scf) | Average Emission Rate (odor units/min) | Remarks |
|---|---|---|---|---|
| Rubber processing | 6,900 | 50 | 350,000 | Controlled by direct fume incinerator |
| Coffee roaster | 3,600 | 2,000 | 7,200,000 | Uncontrolled effluent from roasters |
| Rendering plant | 29,000 | 1,500-25,000 | 55,000,000<br>730,000,000 | Uncontrolled effluent from dryer |
| Pulp mill | 200,000 | <10 | 2,000,000 | Controlled by recovery furnace |
| Pulp mill | 200,000 | 17 | 3,400,000 | Controlled by recovery furnace |
| Pulp mill | 200,000 | 2,000 | 400,000,000 | Recovery furnace intentionally upset |
| Pulp mill | 200,000 | 2,500-11,000 | 500,000,000<br>2,200,000,000 | Effluent from cascade evaporator |

*Based on syringe dilution technique.

## TABLE 22

## ATMOSPHERIC CONTAMINANTS* RECOVERED FROM CHARCOAL AFTER 30-DAY MANNED EXPERIMENT[282]

1. Carbon dioxide
2. Ethylene
3. Acetylene
4. Propylene
5. Butene-1
6. Isobutylene
7. n-Butane
8. Saturated hydrocarbon
9. Freon-11
10. Acetaldehyde
11. Isoprene
12. Hydrocarbon
13. Ethyl formate
14. Hydrocarbon
15. Ethyl alcohol
16. Hydrocarbon
17. Ethyl acetate
18. Benzene
19. Hydrocarbon
20. Trichloroethylene
21. Toluene
22. Tetrachloroethylene
23. Butanol
24. Acetone
25. Hydrocarbon
26. Acetic acid
27. Proprionic acid
28. Butyric acid
29. Formaldehyde

*Detected in the unseparated desorbate mixture of hydrocarbons.

APPENDIX B

### TABLE 23

### POTENTIAL SOURCES OF ODOROUS EMISSIONS FROM OIL REFINERIES[214]

| Emissions | Sources |
|---|---|
| Oxides of sulfur | Combustion of fuels containing sulfur, flares, catalytic cracking unit regenerators, treating units, decoking operations |
| Hydrocarbons | Gasoline storage tanks and loading facilities, turnarounds (blow-down systems, blind changing), leakage (pumps, valves, cooling towers, sampling), sewers and oil recovery facilities, vacuum jets and/or barometric condensers, catalyst regenerators, and compressor engines |
| Oxides of nitrogen | Combustion processes, gas fired compressor engine exhausts, catalyt regenerators, flares |
| Mercaptans | Cracking units, caustic regeneration units, some asphalt plants |
| Hydrogen sulfide | Untreated gas stream leaks; vapor from crude oil and raw distillates, process condensate sewers |
| Phenolic compounds and naphthenic acids | Movement and storage of the caustic solutions used in scrubbing straight run and cracked distillates |
| Organic sulfides and nitrogen bases | Movement and storage of the acid solutions used in scrubbing organic sulfides and nitrogen bases, if they are present, from straight run or cracked distillates or lubricating oil fractions |
| Aldehydes | Air-blowing of asphalts, incomplete combustion of fuel |

## TABLE 24

## CRUDE OIL CAPACITY IN THE UNITED STATES AS OF JANUARY 1969[273]

| State | No. Plants | Crude Capacity[a] | |
|---|---|---|---|
| | | b/cd[b] | b/sd[c] |
| Alabama | 6 | 34,620 | 36,820 |
| Alaska | 1 | 20,000 | 21,000 |
| Arkansas | 6 | 93,500 | 94,985 |
| California | 32 | 1,529,075 | 1,606,985 |
| Colorado | 4 | 42,900 | 46,235 |
| Delaware | 1 | 140,000 | 150,000 |
| Florida | 1 | 3,100 | 3,150 |
| Georgia | 2 | 9,500 | 11,000 |
| Hawaii | 1 | 35,000 | NR |
| Illinois | 11 | 704,100 | 732,300 |
| Indiana | 10 | 565,700 | 588,800 |
| Kansas | 12 | 389,300 | 407,300 |
| Kentucky | 3 | 128,500 | 132,600 |
| Louisiana | 16 | 1,190,850 | 1,230,000 |
| Maryland | 2 | 19,400 | 20,500 |
| Michigan | 8 | 146,050 | 152,000 |
| Minnesota | 3 | 138,300 | 144,000 |
| Mississippi | 4 | 168,700 | 181,500 |
| Missouri | 1 | 83,000 | 84,700 |
| Montana | 9 | 128,200 | 137,500 |
| Nebraska | 1 | 4,000 | 4,500 |
| New Jersey | 6 | 523,500 | 555,000 |
| New Mexico | 6 | 42,610 | 44,400 |
| New York | 2 | 76,900 | 81,000 |
| North Dakota | 2 | 55,000 | 57,000 |
| Ohio | 11 | 491,600 | 525,900 |
| Oklahoma | 14 | 449,367 | 464,250 |
| Oregon | 1 | 11,000 | 12,000 |
| Pennsylvania | 13 | 628,920 | 659,100 |
| Rhode Island | 1 | 7,500 | 10,000 |
| Tennessee | 1 | 28,500 | 29,750 |
| Texas | 47 | 3,118,250 | 3,244,300 |
| Utah | 5 | 11,950 | 116,400 |
| Virginia | 1 | 43,600 | 45,000 |
| Washington | 6 | 219,000 | 226,000 |
| West Virginia | 2 | 8,570 | 9,100 |
| Wisconsin | 2 | 29,500 | 30,600 |
| Wyoming | 9 | 132,900 | 146,686 |
| Total | 263 | 11,522,512 | 12,079,201 |

[a] State totals include figures converted to calendar-day or stream-day basis.

[b] b/cd = barrels per calendar day.

[c] b/sd = barrels per stream-day.

## TABLE 25

## SULFUR PRODUCTION FROM HYDROGEN SULFIDE IN THE UNITED STATES[95,204]

(Long Tons per Year)

| Year | Plant Capacity | Actual Production |
|---|---|---|
| 1961 | 1,659,000 | 858,000 |
| 1967 | 2,737,000 | 1,244,000 |
| 1968 | 3,036,000 | 1,400,000 |

APPENDIX B

## TABLE 26

## RANGE OF SULFUR GAS CONCENTRATIONS ENCOUNTERED IN KRAFT MILL SAMPLING[243]

| | Gas Concentration (ppm by volume) | | | | |
|---|---|---|---|---|---|
| Source | Sulfur Trioxide | Hydrogen Sulfide | Methyl Mercaptan | Dimethyl Sulfide | Dimethyl Disulfide |
| Digester vent | | 16-18,800 | 0-4,370 | 3,850-65,000 | 0-65,000 |
| Blow gases | | 0-782 | 0-9,840 | 522-46,900 | 0-10 |
| Pulp washer | 0.1-0.2 | 0-12 | 0-79 | 0 | 0.1-0.4 |
| Evaporator, noncondensible | | 907-32,600 | 455-36,700 | 0-27,600 | 0-1,278 |
| Recovery furnace | 4-798 | 14-1,140 | 0-489 | 0-260 | 0-17 |
| Smelt dissolving tank | 0.5-70 | 10-44 | 0-212 | 0-91 | 0-4 |
| Lime kiln | 0-169 | 0-254 | 0-128 | 0-60 | 0-18 |
| Tall oil cooking | 2-822 | 5,400-101,000 | 0-4,660 | 0 | 103-7,693 |

TABLE 27

ESTIMATED EMISSIONS FROM KRAFT PULP MILL IN LEWISTON, IDAHO[268]
(Pounds per Day)

| Process or Equipment Source | Hydrogen Sulfide | Methyl Mercaptan | Dimethyl Sulfide | Solid Particulates | Combustibles[a] | Sulfur Oxides as $SO_2$ | Nitrogen Oxides as $NO_2$ | Aldehydes as Formaldehydes | Organic Acids as HAc | Hydrocarbons | Water Vapor |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Digester gases | 9 | 69 | 50 | e | e | e | e | e | e | e | e |
| Evaporators | 390 | 20 | neg | e | e | e | e | e | e | e | e |
| Recovery furnaces | 3,120 | neg | neg | 12,310 | 141,400 | 1,180 | c | e | e | e | 2,778,000 |
| Smelt tanks | c | c | c | 1,100 | e | e | e | e | e | e | e |
| Lime kilns | 737 | c | c | 6,269 | 147,700 | 6[b] | 847 | 8 | 20 | e | 1,850,000 |
| Oxidation towers | c | c | 60 | e | e | e | e | e | e | e | e |
| Plant boilers[d] | e | e | e | 397 | neg | 28[b] | 2,910 | 141 | 92 | 1,285 | 2,550,000 |
| Paper machines | e | e | e | e | e | e | e | e | e | e | 1,782,000 |
| Pulp dryer | e | e | e | e | e | e | e | e | e | e | 320,000 |
| Total | 4,256 | 89 | 110 | 20,076 | 289,100 | 1,214 | 3,757 | 149 | 112 | 1,285 | 9,280,000 |

[a] Combustible emission probably consists of carbon monoxide and other organic materials.
[b] Assumed sulfur content of natural gas, 0.4 grain per 100 $ft^3$.
[c] Indicated pollutant present in emissions, but amount is unknown.
[d] Emissions include those from burning waste wood.
[e] Material below detection or not measured.

APPENDIX B

## TABLE 28

## NOVEMBER ODOR SURVEY IN LEWISTON-CLARKSTON AREA[268]

| Odor Type | Clarkston |  | Clarkston Heights |  | Lewiston |  | Lewiston Orchards |  |
|---|---|---|---|---|---|---|---|---|
|  | 51 Students |  | 7 Students |  | 32 Students |  | 30 Students |  |
|  | Positive Responses | Total Positive Response, % | Positive Responses | Total Positive Response, % | Positive Responses | Total Positive Response, % | Positive Responses | Total Positive Response, % |
| Pulp mill | 238 | 31.2 | 45 | 30.4 | 107 | 48.2 | 52 | 26.5 |
| Wood smoke | 228 | 30.0 | 41 | 27.7 | 76 | 34.2 | 78 | 39.8 |
| Burning leaves | 92 | 12.1 | 8 | 5.4 | 19 | 8.6 | 22 | 11.2 |
| Wet grass, misty | 41 | 5.4 | 5 | 3.4 | 3 | 1.3 | 11 | 5.6 |
| Gasoline, oil, tar | 23 | 3.0 | 4 | 2.7 | 3 | 1.3 | 5 | 2.6 |
| Rotten flesh | 12 | 1.6 | 8 | 5.4 | 1 | 0.5 | 2 | 1.0 |
| Rubbish | 66 | 8.6 | 12 | 8.1 | 5 | 2.3 | 12 | 6.1 |
| Animal odors | 19 | 2.5 | 11 | 7.4 | 0 | 0.0 | 8 | 4.1 |
| Miscellaneous | 43 | 5.6 | 14 | 9.5 | 8 | 3.6 | 6 | 3.1 |
| Total | 762 | 100.0 | 148 | 100.0 | 222 | 100.0 | 196 | 100.0 |

APPENDIX B

## TABLE 29

## APRIL ODOR SURVEY IN LEWISTON-CLARKSTON AREA[268]

| | Clarkston | | Clarkston Heights | | Lewiston | | Lewiston Orchards | |
|---|---|---|---|---|---|---|---|---|
| | 37 Students | | 6 Students | | 37 Students | | 30 Students | |
| Odor Type | Positive Responses | Total Positive Response, % | Positive Responses | Total Positive Response, % | Positive Reponses | Total Positive Response, % | Positive Responses | Total Positive Response, % |
| Pulp mill | 134 | 51.6 | 5 | 10.6 | 63 | 27.7 | 31 | 19.5 |
| Wood smoke | 28 | 10.8 | 14 | 29.8 | 39 | 17.2 | 41 | 25.8 |
| Burning leaves | 7 | 2.7 | 0 | 0.0 | 4 | 1.8 | 10 | 6.3 |
| Wet grass, misty | 2 | 0.8 | 7 | 14.9 | 12 | 5.3 | 9 | 5.7 |
| Gasoline, oil, tar | 4 | 1.5 | 0 | 0.0 | 28 | 12.3 | 4 | 2.5 |
| Rotten flesh | 6 | 2.3 | 0 | 0.0 | 1 | 0.4 | 1 | 0.6 |
| Rubbish | 42 | 16.2 | 5 | 10.6 | 10 | 4.4 | 4 | 2.5 |
| Animal odors | 5 | 1.9 | 2 | 4.3 | 5 | 2.2 | 12 | 7.5 |
| Miscellaneous | 32 | 12.3 | 14 | 29.8 | 65 | 28.6 | 47 | 29.6 |
| Total | 260 | 100.0 | 47 | 100.0 | 227 | 100.0 | 159 | 100.0 |

## TABLE 30

## KRAFT PULP PRODUCTION IN THE UNITED STATES[222]

| Year | Million Tons/Year |
|---|---|
| 1957 | 12.8 |
| 1958 | 13.1 |
| 1959 | 14.9 |
| 1960 | 15.3 |
| 1961 | 16.1 |
| 1962 | 17.4 |
| 1963 | 18.7 |
| 1964 | 20.4 |
| 1965 | 22.3 |
| 1966 | 24.4 |
| 1967 | 23.9 |

APPENDIX B

TABLE 31

SOURCES OF ODOROUS EMISSIONS IN COKE PLANTS[231]

| Source of Emission | Cause of Emission |
|---|---|
| **Condensation** | |
| Unburnt gases escaping from the gas torches | |
| In normal operation with torch shut off | Leakage at stop valves |
| With torch open during operational failures | Failure of ignition device |
| Gases escaping from water seals | Defective seals |
| Outflow collectors on coolers; collector and separator tanks | Gas escape from liquids |
| **Ammonia Scrubber** | |
| Outflow collectors and collector tanks | Gas escape from washing of fluid |
| Secondary coolers for primary-cooler outflow (in semi-direct process) | Escape of hydrogen sulfide with the cooling-tower vapors |
| **Benzol Scrubber and Plant** | |
| Outflow receivers of scrubbers and washing oil tanks | Gas escape from washing fluid |
| Cooler-ventilating lines | Escape of sulfur-containing compounds with low boiling point, together with ventilating gases |
| **Desulfurization of Gas** | |
| Outflow receivers and tanks for scrubbing fluid | Gas escape from washing fluid |

## TABLE 32

## ODOR CONCENTRATIONS AND EMISSION RATES FROM INEDIBLE REDUCTION PROCESSES[51]

| Source | Odor Concentration (odor unit/scf) | | Typical Moisture Content of Feeding Stocks (%) | Exhaust Products (scf/ton of feed[a]) | Odor Emission Rate | |
|---|---|---|---|---|---|---|
| | Range | Typical Avg | | | Odor unit/ton of feed | Odor unit/min |
| Rendering cooker, dry-batch type[b] | 5,000 to 500,000 | 50,000 | 50 | 20,000 | 1,000 x $10^6$ | 25,000,000 |
| Blood cooker, dry-batch type[b] | 10,000 to 1 million | 100,000 | 90 | 38,000 | 3,800 x $10^6$ | |
| Feather drier, steamtube[c] | 600 to 25,000 | 2,000 | 50 | 77,000 | 153 x $10^6$ | 50,000,000 |
| Blood spray drier[c,d] | 600 to 1,000 | 800 | 60 | 100,000 | 80 x $10^6$ | 25,000,000 |
| Grease-drying tank, air blowing | | | <5 | 100 scfm per tank | | |
| 156°F | | 4,500 | | | | |
| 170°F | | 15,000 | | | | |
| 225°F | | 60,000 | | | | |

[a] Assuming 5 percent moisture in solid products of system.
[b] Noncondensible gases are neglected in determining emission rates.
[c] Exhaust gases are assumed to contain 25 percent moisture.
[d] Blood handled in spray drier before any appreciable decomposition occurs.

TABLE 33

TYPICAL ODOR EMISSIONS FROM ROTARY FISH MEAL DRIERS WITHOUT ODOR CONTROL[179]

| Drier | Feed Rate (tons per hour) | Type of Scrap | Temp at Drier Discharge °F | Exhaust Gas Volume (scf per min[a]) | Odor Concentration (odor units per scf[b]) | Odor Emission Rate (odor units per min) | Odor Emission Rate (odor units per ton of feed) |
|---|---|---|---|---|---|---|---|
| A | 10 | Tuna | 220 | 18,500 | 1,500 | $27.8 \times 10^6$ | $167 \times 10^6$ |
| A | 15 | Mackerel | 220 | 18,500 | 1,500 | $27.8 \times 10^6$ | $111 \times 10^6$ |
| B | 7 | Tuna | 220 | 9,000 | 700 | $6.3 \times 10^6$ | $54 \times 10^6$ |
| B | 10 | Tuna | 240 | 10,000 | 1,500 | $15 \times 10^6$ | $90 \times 10^6$ |
| B | 14 | Tuna | 300 | 8,000 | 4,000 | $32 \times 10^6$ | $137 \times 10^6$ |
| C | 9 | Tuna | 200 | 17,000 | 2,500 | $42.5 \times 10^6$ | $284 \times 10^6$ |
| D | 6 | Tuna | 180 | 9,800 | 2,000 | $19.6 \times 10^6$ | $196 \times 10^6$ |

[a] Standard cubic feet per minute.

[b] Odor units per standard cubic foot (70°F and 14.7 psia).

APPENDIX B

## TABLE 34

## ODOR EMISSIONS FROM APARTMENT HOUSE INCINERATORS[138]

| | Test Number | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Odor units per scf | 2.5 | 14 | 5 | 100 | 8 |
| Dry flue gas, scf x 1,000 | 263 | 211 | 618 | 131 | 144 |
| Total odor units x 1,000 | 657 | 2,950 | 3,090 | 13,100 | 1,150 |
| Odor units x 1,000 per 100 lb refuse | 240 | 1,070 | 755 | 5,000 | 930 |
| Burning rate, 100 lb/hr | 1.22 | 1.38 | 0.546 | 1.74 | 0.620 |
| Odor units x 1,000 per min | 4.90 | 24.7 | 6.92 | 145 | 9.63 |

## TABLE 35

## ODOR INTENSITY OF DIESEL EXHAUST AND CONCENTRATION OF ALDEHYDES (AS FORMALDEHYDE)

| | | Aldehyde Concentration, ppm (as HCHO)* | | |
|---|---|---|---|---|
| Odor Strength | Odor Intensity | Reference 239 | Reference 72 | Reference 297 |
| 0 | No odor | | | 7.1 |
| 1 | Very faint | .52 | .95 | 12 |
| 2 | Faint | 5.5 | 4 | 21 |
| 3 | Easily noticeable | 48 | 18 | 35 |
| 4 | Strong | 420 | 80 | 60 |
| 5 | Very strong | | | 100 |

*Smoothed values.

APPENDIX B

## TABLE 36

## COMPUTED CONCENTRATIONS AT ODOR THRESHOLDS OF DILUTED DIESEL EXHAUST[156]

| Subject | Trials | Odor Units/scf[a] of Diesel Exhaust | ppm $NO_2$[b] | ppm CH[b,c] | ppm Acrolein[b] | ppm Formaldehyde[b] |
|---|---|---|---|---|---|---|
| I. 500 rpm, ZERO LOAD | | | | | | |
| A | 4 | 215 | 0.20 | 0.27 | 0.019 | 0.021 |
| B | 4 | 385 | 0.11 | 0.15 | 0.010 | 0.012 |
| C | 3 | 205 | 0.21 | 0.28 | 0.020 | 0.022 |
| D | 4 | 140 | 0.31 | 0.42 | 0.029 | 0.033 |
| E | 6 | 190 | 0.23 | 0.31 | 0.021 | 0.024 |
| F | 5 | 360 | 0.12 | 0.16 | 0.011 | 0.013 |
| Avg | | 249 | 0.20 | 0.26 | 0.018 | 0.021 |
| II. 1,600 rpm, FULL LOAD | | | | | | |
| A | 7 | 450 | 0.89 | 0.10 | 0.018 | 0.034 |
| B | 8 | 475 | 0.84 | 0.09 | 0.017 | 0.032 |
| C | 4 | 215 | 1.85 | 0.21 | 0.038 | 0.072 |
| D | 4 | 175 | 2.28 | 0.26 | 0.046 | 0.088 |
| E | 6 | 195 | 2.05 | 0.23 | 0.042 | 0.079 |
| F | 3 | 320 | 1.25 | 0.14 | 0.025 | 0.048 |
| Avg | | 305 | 1.53 | 0.17 | 0.031 | 0.059 |

[a] Volume of dilution air per volume of raw diesel exhaust at the odor threshold.

[b] Computed by dividing concentration values by the odor units/scf. Odor thresholds of nitrogen dioxide, acrolein, and formaldehyde are 4.0, 0.4-6.6, and 0.2-1.8, respectively.

[c] Calculated from 3.4 μ infrared band as hexane.

## TABLE 37

## ANALYSIS OF DIESEL ENGINE EXHAUST[61]

| | | Engine A[a] Exhaust | | | | Engine B[b] Exhaust | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Idle | | Half Load | | Idle | | Full Load | |
| | | Fuel E[d] | Fuel F[e] | Fuel E | Fuel F | Fuel E | Fuel F | Fuel E | Fuel F |
| Formaldehyde, ppm | Avg | 34.9 | 32.3 | 9.2 | 12.1 | 12.6 | 10.4 | 19.3 | 23.3 |
| | SD[c] | 2.0 | 4.5 | 1.0 | 1.2 | 1.6 | 2.1 | 3.7 | 2.0 |
| Acrolein, ppm | Avg | 8.0 | 8.4 | 2.1 | 2.8 | 3.9 | 3.7 | 4.1 | 5.0 |
| | SD | 0.9 | 1.4 | 0.5 | 0.4 | 0.5 | 0.7 | 0.6 | 1.0 |
| Total aldehydes, ppm | Avg | 56.4 | 58.8 | 13.8 | 17.3 | 18.3 | 15.2 | 30.3 | 25.3 |
| | SD | 3.0 | 3.9 | 0.8 | 1.4 | 1.6 | 3.6 | 1.0 | 5.4 |
| Total carbonyls, ppm | Avg | 165.0 | 149.3 | 270.0 | 220.7 | 49.5 | 56.5 | 93.6 | 97.0 |
| | SD | 20.2 | 13.6 | 36.3 | 20.4 | 10.4 | 11.2 | 4.5 | 9.0 |
| Total unsaturation, ppm | Avg | 75.5 | 54.5 | 130.8 | 111.2 | 18.2 | 19.0 | 43.2 | 56.6 |
| | SD | 6.4 | 6.1 | 16.3 | 26.2 | 3.2 | 3.9 | 9.9 | 19.1 |
| $NO_x$, ppm | Avg | 288 | 256 | 1,635 | 1,651 | 130 | 142 | 1,121 | 1,159 |
| | SD | 21 | 18 | 42 | 47 | 10 | 17 | 108 | 84 |
| Color, ml | Avg | 15.0 | 16.1 | 1.9 | 2.0 | 4.7 | 4.5 | 5.0 | 4.5 |
| | SD | 1.0 | 2.2 | 0.3 | 0.0 | 0.4 | 0.5 | 0.2 | 0.6 |
| | | | | ODOR AT DILUTION, ODOR UNITS | | | | | |
| Threshold | | 8,000 | 6,900 | 7,800 | 7,200 | 7,900 | 7,500 | 8,800 | 8,400 |
| Diesel identification | | 4,400 | 3,550 | 4,180 | 3,700 | 4,100 | 2,650 | 4,500 | 4,800 |
| Objectional | | 1,650 | 1,650 | 1,380 | 1,650 | 1,300 | 800 | 1,450 | 1,780 |

---

[a] Engine A: four-cycle engine.
[b] Engine B: two-cycle engine.
[c] SD: Standard deviation.
[d] Fuel E: No. 1 grade.
[e] Fuel F: No. 2 grade.

## TABLE 38

## DIESEL EXHAUST EMISSIONS AND PERCENT OF TIME AT EACH POWER SETTING FOR TWO-CYCLE DIESEL BUS OPERATING IN DETROIT[159]

| Power Setting | Exhaust Flow (scfm) | Percent of Time | CO (ppm) | Hydrocarbons as $CH_4$ (ppm) | Nitrogen Oxides as $NO_2$ (ppm) | Odor Dilution Threshold[a] | Odor Emission Rate[b] |
|---|---|---|---|---|---|---|---|
| Idle | 120 | 57.5 | 160 | 340 | 160 | 330 | 39,500 |
| 32 mph, 25 hp | 408 | 21.5 | 145 | 457 | 305 | 440 | 180,000 |
| 35 mph, 65 hp | 630 | 7.7 | 617 | 570 | 650 | 540 | 340,000 |
| 51 mph, 122 hp | 640 | 13.3 | 850 | 750 | 810 | 790 | 505,000 |

[a] Odor units/scf.

[b] Odor units/min.

## TABLE 39

## ODOR EMISSIONS FROM JET AIRCRAFT EXHAUST [159]

| Engine Type | Power(%) | Normal Use | Odor Units/scf |
|---|---|---|---|
| T-56-A7<br>(Turboprop) | 100 | Take-off | 100 |
| | 75 | Cruise and approach | |
| | 65 | Idle | 75 |
| T-57-19W<br>(Conventional jet) | 100 | Take-off | 600 |
| | 75 | Cruise | 660 |
| | 65 | Idle | 15 |
| TF-33-P5<br>(Fan jet) | 100 | Take-off | 75 |
| | 75 | Approach | 500 |
| | 65 | Idle | 1000 |

## TABLE 40

## NUMBER, TYPE, AND LOCATION OF ODOR OBSERVATIONS NEAR JOHN F. KENNEDY AIRPORT[201]

| | Total Observations by Zones[a] | | | |
|---|---|---|---|---|
| Type of Odor | 1 | 2 | 3 | 4 |
| Total number of observations | 238 | 260 | 335 | 198 |
| Total number of positive observations | 62 | 65 | 146 | 61 |
| Percentage of positive observations[b] | 26.1 | 25.0 | 43.6 | 30.8 |
| 1. Chemical odors (including chemical, sulfurous, soap or detergent, refinery, medicinal, vanilla or coumarin, bleach or chlorine, ammonia, other) | 1 | 3 | 1 | 2 |
| Percentage of positive observations[c] | 1.6 | 4.6 | 0.68 | 3.3 |
| 2. Food processing odors (including coffee roasting, bakery, brewery, restaurant, grain, smoking fish, other, unknown) | 1 | 1 | 1 | 1 |
| Percentage of positive observations[c] | 1.6 | 1.5 | 0.68 | 1.6 |
| 3. Combustion odors including the following: | 10 | 36 | 46 | 22 |
| Gasoline and diesel engine exhaust | 0 | 0 | 11 | 5 |
| Coke-oven and coal gas odors (steel mills) | 2 | 0 | 0 | 6 |
| Maladjusted heating systems | 0 | 3 | 2 | 0 |
| Coal smoke | 6 | 0 | 1 | 0 |
| Smokey | 0 | 13 | 23 | 8 |
| Other | 2 | 4 | 0 | 3 |
| Unknown | 0 | 15 | 9 | 0 |
| Jet exhaust smoke or odor | 0 | 0 | 0 | 0 |
| Percentage of positive observations[c] | 16.1 | 55.4 | 31.5 | 36.1 |
| 4. General industrial odors (including asphalt, plastics, solvents, fertilizer plants, paint and related industries, oily, fuel odor, other, unknown) | 11 | 2 | 0 | 8 |
| Percentage of positive observations[c] | 17.7 | 3.1 | 0 | 13.1 |

(continued)

### TABLE 40 (Continued)

### NUMBER, TYPE, AND LOCATION OF ODOR OBSERVATIONS NEAR JOHN F. KENNEDY AIRPORT

| | Total Observations by Zones[a] | | | |
|---|---|---|---|---|
| Type of Odor | 1 | 2 | 3 | 4 |
| 5. Animal odors (including rendering, stockyards, poultry, fish, organic fertilizer, meat processing plant, other, unknown) | 0 | 1 | 3 | 7 |
| Percentage of positive observations[c] | 0 | 1.5 | 2.1 | 11.5 |
| 6. Odors from combustible waste (including open-dump fires, city incinerators burning garbage, home incinerators, backyard trash fires and wood smoke, burning rubber, other, unknown) | 14 | 5 | 14 | 6 |
| Percentage of positive observations[c] | 22.6 | 7.7 | 9.6 | 9.8 |
| 7. Decomposition odors (including sewage, nonburning garbage, other, unknown) | 2 | 1 | 1 | 9 |
| Percentage of positive observations[c] | 3.2 | 1.5 | 0.68 | 14.8 |
| 8. Vegetation odors (including general, freshly cut wood, flowers and/or flowering shrubs, marshland odor, fresh fruit odors, plowed or excavated soil) | 22 | 11 | 14 | 4 |
| Percentage of positive observations[c] | 35.5 | 16.9 | 9.6 | 6.6 |
| 9. Miscellaneous odors (including general, foul--not specified, putrid--source not specified, not pleasant, smog, clean or fresh, ocean smell, dust, tobacco) | | | | |
| Percentage of positive observations[c] | 1.6 | 7.7 | 45.2 | 3.3 |

a. Zones 1, 2, 3, and 4 are all within 3 miles of the airport premises and in a northerly direction from the airport. Zones 1 and 4 are in NNW direction, zone 2 in a N direction, and Zone 3 in a NNE direction.

b. $\frac{\text{Total number of positive observations}}{\text{Total number of observations}} \times 100$

c. $\frac{\text{Number of odor types observed}}{\text{Total number of positive observations}} \times 100$

TABLE 41

CONTROL OF ODORS BY INCINERATION[26]

| Application | Incinerator Temperature ($^{o}F$) | Average Odor Concentration* in Incinerator (odor units/scf) Inlet | Outlet | Exhaust Gas Flow (scfm) | Effect of Incineration on Odor Strength (% reduction) |
|---|---|---|---|---|---|
| Wire enameling | 1,000 | 1,300 | 2,100 | | -61 |
| Oven, portable unit | 1,200 | 2,500 | 350 | | 86 |
| Field test | 1,400 | 1,300 | 70 | | 97 |
| Glass fiber | 1,009 | 550 | 625 | 14,000 | -14 |
| Curing-oven field | 1,250 | 380 | 53 | 14,000 | 86 |
| | 1,352 | 255 | 25 | 14,000 | 90 |
| Abrasive wheel | 1,200 | 800 | 10 | | 98 |
| Curing-oven laboratory test | 1,400 | 1,600 | 32 | | 98 |
| Test 1 | | | | | |
| Automobile paint | 1,350 | 260 | 14 | | 95 |
| Bake-oven field test | 1,450 | 170 | 10 | | 94 |
| Test 2 | 1,350 | 650 | 10 | | 93 |
| | 1,450 | 680 | 18 | | 97 |
| Hard-board curing | 1,400 | 1,000 | 40 | | 96 |
| Oven laboratory test | 1,500 | 1,400 | 15 | | 98 |

*Based on syringe dilution technique.

APPENDIX B

TABLE 42. ODOR EMISSIONS FROM TYPICAL INDUSTRIAL EQUIPMENT AND ODOR CONTROL DEVICES[137]

| Type of Equipment or Operation | Odor Levels and Emission Rates, Uncontrolled |  | Odor Levels and Emission Rates, Controlled |  |  |  |
|---|---|---|---|---|---|---|
|  | Vent Gas Odor Concentration Range (ou/scf$^a$) | Model Odor Emission Rate (ou/min$^b$) | Type of Odor Control Equipment | Vent Gas Odor Concentration (ou/scf$^a$) | Odor Emission Rate (ou/min$^b$) | Temperature$^c$ and Efficiency$^d$ |
| Rendering cooker (Inedible charge) Dry batch type | 5,000 to 500,000$^e$ (Mode 50,000) | 25,000,000 | Direct-Fired(DF)* | 100 to 150 (Mode 120) | 90,000 | 1,200°F 99+% |
|  |  |  | Surface condenser** | 100,000 to 10,000,000$^f$ (Mode 500,000) | 12,000,000 | 80°F Negative$^f$ |
|  |  |  | Jet condenser followed by a D-F after-burner* | 20 to 50 (Mode 25) | 2,000 | 1,200°F 99+% |
|  |  |  | Surface condenser followed by a D-F after-burner* | 50 to 100 (Mode 75) | 6,000 | 1,200°F 99+% |
|  |  |  | Jet (or contact condenser)** | 2,000 to 20,000 (Mode 10,000) | 70,000 | 80°F 80% |
| Rendering Cooker (Blood drying) Dry batch type | 10,000 to 1,000,000$^g$ | Not measured |  |  |  |  |
| Rendering cooker (Edible charge)<br>Dry batch type<br>Wet batch type<br>Continuous type | <br>2,500$^h$<br>350$^h$<br>650 to 7,000$^{h,i}$ | <br>70,000$^h$ |  |  |  |  |

(continued)

APPENDIX

TABLE 42. ODOR EMISSIONS FROM TYPICAL INDUSTRIAL EQUIPMENT AND ODOR CONTROL DEVICES[137] (Continued)

| Type of Equipment or Operation | Odor Levels and Emission Rates, Uncontrolled | | Odor Levels and Emission Rates, Controlled | | | |
|---|---|---|---|---|---|---|
| | Vent Gas Odor Concentration Range (ou/scf[a]) | Model Odor Emission Rate (ou/min[b]) | Type of Odor Control Equipment | Vent Gas Odor Concentration (ou/scf[a]) | Odor Emission Rate (ou/min[b]) | Temperature[c] and Efficiency |
| Fish-meal drier | 1,000 to 5,000 (Mode 2,000) | 50,000,000 | Packed column type scrubber** | 200 to 1,000 (Mode 400) | 10,000,000 | 70°F 80% |
| | | | Chlorination[k] plus packed column scrubber** | 30 to 50 (Mode 40) | 1,000,000 | 70°F 98% |
| Air blowing of fish oils | 10,000 to 70,000 (Mode 50,000) (Estimated) | 30,000,000 | Direct-fired afterburner* | 25 to 75 (Mode 50) (Estimated) | 50,000[l] | 1,200°F 99+% |
| Air blowing of linseed oil | 120,000[h] | Not measured | Direct-fired afterburner* | 2,000 | Not measured | 1,200°F 97.5% |
| Varnish cooker batch type | 10,000 to 200,000[e] (Mode 25,000) | 10,000,000 | Recirculating spray contact scrubber followed by a DF afterburner* | 10 to 25 (Mode 20) | 10,000 | 1,200°F 99+% |
| | | | Recirculating spray (contact) scrubber** | 20,000 | Not measured | |
| | | | Direct fired afterburner* | 100 to 400 (Mode 250) | 100,000 | 1,200°F 99% |
| | | | Recirculating spray (contact) scrubber** | 100,000[h] | Not measured | |

(continued)

TABLE 42. ODOR EMISSIONS FROM TYPICAL INDUSTRIAL EQUIPMENT AND ODOR CONTROL DEVICES (Continued)

| Type of Equipment or Operation | Odor Levels and Emission Rates, Uncontrolled | | Odor Levels and Emission Rates, Controlled | | | |
|---|---|---|---|---|---|---|
| | Vent Gas Odor Concentration Range (ou/scf[a]) | Model Odor Emission Rate (ou/min[b]) | Type of Odor Control Equipment | Vent Gas Odor Concentration (ou/scf[a]) | Odor Emission Rate (ou/min[b]) | Temperature[c] and Efficiency |
| Lithographing oven metal decorating | 700 to 10,000[j]<br>(Mode 3,000) | 15,000,000 | Direct-fired afterburner* | 50 to 500<br>(Mode 200) | 1,200,000 | 1,200°F<br>95% |
| | | | Catalytic afterburner* | 450[h]<br>3,000[h] | 2,300,000 | 1,000°F[m]<br>800°F |
| Coffee roaster batch type | 300 to 30,000[e] | 3,000,000[h]<br>(Estimated) | Direct-fired afterburner* | 150 to 15,000[n] | 1,700,000[h]<br>(Estimated) | 1,100°F<br>50% |
| Coffee roaster continuous type | 500 to 1,000[j]<br>(Mode 1,000)<br>(Estimated) | 3,000,000[l] | Direct-fired afterburner* | 300 to 1,000<br>(Mode 350)<br>(Estimated) | 1,200,000[l] | 900°F<br>65% |
| Bread baking oven | 1,000[h] | Not measured | | | | |
| Tallow hydrolyzer ("Fat splitter") | Not measured | Not measured | Surface condenser[o] followed by a direct-fired afterburner* | 2,000,000<br>2,000<br>750<br>150<br>70 | Not measured | 940°F<br>1,100°F<br>1,200°F<br>1,300°F<br>1,400°F |
| | | | Surface condenser** | 6,000 | Not measured | |

(continued)

TABLE 42. ODOR EMISSIONS FROM TYPICAL INDUSTRIAL EQUIPMENT AND ODOR CONTROL DEVICES (Continued)

| Type of Equipment or Operation | Odor Levels and Emission Rates, Uncontrolled | | Odor Levels and Emission Rates, Controlled | | | |
|---|---|---|---|---|---|---|
| | Vent Gas Odor Concentration Range (ou/scf[a]) | Model Odor Emission Rate (ou/min[b]) | Type of Odor Control Equipment | Vent Gas Odor Concentration (ou/scf[a]) | Odor Emission Rate (ou/min[b]) | Temperature[c] and Efficiency |
| Phthalic anhydride manufacturing unit | 1,800 to 3,500[j] (Mode 2,500) | 15,000,000 | Direct-fired afterburner* | 45 to 120 (Mode 75) | 500,000 | 1,200°F 97% |
| | | | Catalytic afterburner* | 1,800 | 11,000,000 | 745°F 27% |
| | | | Catalytic afterburner* | 180 | 1,100,000 | 815°F[m] 93% |

*Afterburner odor control devices.

**Nonafterburner odor control devices.

[a] Odor units per standard cubic foot (at 70°F and 14.7 psia).

[b] Odor units discharged per minute, based on average volumetric discharge rate and modal odor concentration.

[c] Temperature of gases after leaving flame-contact zone (afterburners); temperature of vent gases in other cases.

[d] Odor control efficiency, on a modal odor concentration basis.

[e] Odor concentrations in batch processes vary with materials charged and phase of operation.

[f] Surface condensers increase odor concentrations in the vent gases but reduce total odor emission rates.

[g] Hundred-fold increase from beginning to end of cycle.

[h] One test only.

[i] Samples collected from several points of odor emissions.

[j] In continuous processes, odor concentrations vary with temperatures maintained and materials charged.

[k] Chlorine (20 ppm) mixed with drier off-gases, which are then scrubbed. More or less chlorine increases odor concentrations.

[l] Estimated from two tests only.

[m] Maximum temperature at which this catalytic unit can operate.

[n] Outlet odor concentration rises and falls with inlet odor concentration.

[o] The surface condenser is an integral part of the hydrolyzing unit. Note that low temperature incineration increases odor concentration above condenser vent level.

### TABLE 43

### ODOR REMOVAL EFFICIENCIES OF CONDENSERS OR AFTERBURNERS, OR BOTH, VENTING A TYPICAL DRY RENDERING COOKER*[180]

| Concentration (odor units/scf) | Emission Rate (odor units/min) | Condenser Type | Condensate Temperature (°F) | Afterburner Temperature (°F) | Concentration (odor units/scf) | Modal Emission Rate (odor units/min) | Odor Removal Efficiency (%) |
|---|---|---|---|---|---|---|---|
| 50,000 | 25,000,000 | None | | 1,200 | 100 to 150 (Mode 120) | 90,000 | 99.40 |
| | | Surface | 80 | None | 100,000 to 10 million (Mode 500,000) | 12,500,000 | 50 |
| | | Surface | 140 | 1,200 | 50 to 100 (Mode 75) | 6,000 | 99.98 |
| | | Contact | 80 | None | 2,000 to 20,000 (Mode 10,000) | 250,000 | 99 |
| | | Contact | 140 | 1,200 | 20 to 50 (Mode 25) | 2,000 | 99.99 |

*Based on a hypothetical cooker that emits 500 scfm of vapor containing 5 percent noncondensible gases.

### TABLE 44

### ODOR REDUCTION IN POLLUTED AIR BY POTASSIUM PERMANGANATE

| Pollutant | Odorant Concentration Odor Units/scf Solution 1[b] | Odorant Concentration Odor Units/scf Solution 2[c] |
|---|---|---|
| MERCAPTANS | | |
| Butanethiol | 200,000 | 33[a] |
| Pentanethiol | >100,000 | 16[a] |
| Hexanethiol | 85,000 | 10.5[a] |
| Heptanethiol | 3,200 | 20[a] |
| Octanethiol | 3,500 | 6.5[a] |
| OTHER SULFUR COMPOUNDS | | |
| Mercaptoacetic acid | 65 | 1 |
| 2-Mercaptoethanol | 30 | 1 |
| Allyl isothiocyanate | 2,500 | 1 |
| Thiophenol | 1,300 | 13[a] |
| Thiophene | 4,000 | 13[a] |
| AMINES | | |
| Dimethylamine | 1,300 | 20 |
| Trimethylamine | 2,700 | 20 |
| Triethylamine | 60-70 | 50-65[a] |
| Cadaverine | 20 | 1 |
| Indole | 5 | 1 |
| Skatole | 60-100 | 1 |
| PHENOLS | | |
| Phenol | 11 | 1 |
| o-Cresol | 20 | 1 |
| o-Chlorophenol | 200 | 1 |
| m-Chlorophenol | 45 | 25[a] |
| p-Chlorophenol | 5 | 1 |
| MISCELLANEOUS ORGANIC COMPOUNDS | | |
| Styrene | 2,000 | 10[a] |
| Allyl acetate | 1,700 | 25[a] |
| Acrolein | 140,000 | 1 |
| Benzaldehyde | 80 | 1 |
| Acetaldehyde | 1,700 | 200 |
| 1-Butanol | 150 | 40[a] |
| Off-gas of bone elevators (rendering plant) | 100-140 | 20-25[a] |
| Cooker condensate (rendering plant) | 4,000 | 250[a] |
| Off-gas of asphalt plant | 15-20 | 1 |

---

[a] Residual odor characteristics much improved.

[b] Malodorous air bubbled through water, pH 8.5.

[c] Malodorous air bubbled through 1% solution of potassium permanganate, pH 8.5.

APPENDIX B

### TABLE 45

### TYPICAL COSTS OF BASIC AND CONTROL EQUIPMENT INSTALLED IN LOS ANGELES COUNTY[44]

| Source | Size of Equipment | Cost of Basic Equipment | Type of Control Equipment | Cost of Control Equipment |
|---|---|---|---|---|
| Airblown asphalt system | 500 bl/batch | $ 10,000 | Afterburner | $ 3,000 |
| Bulk gasoline loading rack | 667,000 gal/day | 88,000 | Vapor control system | 50,000 |
| Catalytic reforming unit | 2,400 bl/day | 265,000 | Flare and sour water oxidizer | 6,000 |
| Chip dryer | 2,500 lb/hr | 3,000 | Afterburner | 3,000 |
| Chrome plating | 4 by 5 by 5 ft | 2,000 | Scrubber | 800 |
| Coffee roaster | 3 tons/hr | 35,000 | Cyclone and afterburner | 8,000 |
| Core oven | 8 by 8 by 12 ft | 4,000 | Afterburner | 1,500 |
| Crude oil distillation unit | 37,000 bl/hr | 3,060,000 | Vapor control system | 10,000 |
| Debonder | 500 brake shoes/hr | 1,800 | Afterburner | 300 |

(continued)

## TABLE 45 (Continued)

## TYPICAL COSTS OF BASIC AND CONTROL EQUIPMENT INSTALLED IN LOS ANGELES COUNTY

| Source | Size of Equipment | Cost of Basic Equipment | Type of Control Equipment | Cost of Control Equipment |
|---|---|---|---|---|
| Deep fat fryer, food | 1,000 lb/hr | $ 15,000 | Afterburner | $ 1,500 |
| Delayed coker unit | 9,300 bl/day | 4,000,000 | Scrubber (serving 3 cokers) | 385,000 |
| Drum reclamation incinerator | 60 bl/hr<br>200 bl/hr | 10,000<br>25,000 | Afterburner<br>Afterburner | 2,000<br>5,000 |
| Fixed roof storage tank for gasoline | 80,000 bl | 50,000 | New floating roof tank | 132,000 |
| Flue-fed incinerator | Most sizes | 4,000-7,000 | Afterburner | 2,500 |
| Insulation production, including cupola, blow chamber, and curing oven | 5,000 lb/hr | 13,000 | Baghouse, scrubber and afterburner | 30,000 |
| Lithographing oven | 240 ft/min | 78,000 | Afterburner | 15,000 |
| Multiple-chamber incinerator, industrial and commercial | 50 lb/hr<br>500 lb/hr<br>6,000 lb/hr | 800<br>6,500<br>75,000 | | |

(continued)

TABLE 45 (Continued)

TYPICAL COSTS OF BASIC AND CONTROL EQUIPMENT INSTALLED IN LOS ANGELES COUNTY

| Source | Size of Equipment | Cost of Basic Equipment | Type of Control Equipment | Cost of Control Equipment |
|---|---|---|---|---|
| Multiple-chamber incinerator, pathological | 50 lb/hr<br>200 lb/hr | $ 1,000<br>4,500 | | |
| Multiple-chamber incinerator, wire reclamation | 100 lb/hr<br>1,000 lb/hr | 1,200<br>15,000 | | |
| Multiple-chamber incinerator, with continuous feed bin | 250 lb/hr<br>3,000 lb/hr | 5,000<br>45,000 | | |
| Natural gas plant | 20,000,000 $ft^3$/day | 220,000 | Vapor manifold and flare | $ 5,000 |
| Oil-water separator | 300,000 bl/day | 170,000 | Floating roof | 80,000 |
| Phthalic anhydride manufacturing plant | 25,000,000 lb/yr | 1,200,000 | Afterburner and baghouse | 195,000 |
| Pot furnace, type metal | 16,000 lb | 9,000 | Afterburner | 3,000 |

(continued)

## TABLE 45 (Continued)

## TYPICAL COSTS OF BASIC AND CONTROL EQUIPMENT INSTALLED IN LOS ANGELES COUNTY

| Source | Size of Equipment | Cost of Basic Equipment | Type of Control Equipment | Cost of Control Equipment |
|---|---|---|---|---|
| Rendered grease processing | 6 tons/day | $ 10,000 | Contact condenser and afterburner | $ 2,500 |
| Rendering cooker and drier (batch) | 4 tons/batch | 10,000 | Surface condenser and afterburner | 15,000 |
| Rendering cooker system (continuous) | 15 tons/hr | 100,000 | Surface condenser and afterburner | 25,000 |
| Rotogravure press | 5-color, 44-inch web | 340,000 | Activated carbon filter | 40,000 |
| Sewage treatment digestion | 900,000 gal/day | 800,000 | Water seals and flares | 7,000 |
| Sewage treatment headworks | 250,000,000 gal/day | 550,000 | Covers | 20,000 |
| Sewage water reclamation | 17,000,000 gal/day | 1,500,000 | Covers and aeration tanks | 25,000 |

(continued)

APPENDIX B

## TABLE 45 (Continued)

## TYPICAL COSTS OF BASIC AND CONTROL EQUIPMENT INSTALLED IN LOS ANGELES COUNTY

| Source | Size of Equipment | Cost of Basic Equipment | Type of Control Equipment | Cost of Control Equipment |
|---|---|---|---|---|
| Smoke generator and smokehouse | 11 by 14 by 11 ft | $ 18,000 | Precipitator, scrubber, and afterburner | $ 42,000 |
| Sulfur recovery plant | 2 parallel units, 65 tons/day each | 1,400,000 | Incinerator | 30,000 |
| | 10 tons/day | 265,000 | Incinerator | 5,000 |
| | 2,840 lb/day | 30,000 | Incinerator | 1,000 |
| | 8,000 lb/day | 60,000 | Incinerator | 1,000 |
| Synthetic rubber manufacturing | 30,000 tons/year | 1,600,000 | Vapor manifold and flare | 250,000 |
| Synthetic solvent dry cleaner | 60 lb/batch | 14,000 | Activated carbon filter | 3,000 |
| Varnish cookers (2) | 250 gal/each | 4,000 | Afterburner | 5,500 |

(continued)

APPENDIX B

## TABLE 46

## CONTROL EXPENDITURES BY TYPES OF EMISSIONS IN THE PETROLEUM INDUSTRY[71]
(Thousands of Dollars)

| Year | Sulfur Compounds | Hydrocarbons (Combustion) | Hydrocarbons (Recovery) | Smoke and Particulates | Odors and Fumes | Total |
|---|---|---|---|---|---|---|
| 1956 | $ 6,154 | $ 4,977 | $ 5,325 | $ 2,150 | $ 1,171 | $ 19,777 |
| 1957 | 6,154 | 4,977 | 5,325 | 2,150 | 1,171 | 19,777 |
| 1958 | 4,087 | 2,235 | 7,628 | 449 | 981 | 15,380 |
| 1959 | 2,693 | 3,640 | 3,124 | 2,780 | 1,091 | 13,328 |
| 1960 | 4,495 | 2,230 | 7,152 | 780 | 1,047 | 15,704 |
| 1961 | 5,560 | 1,501 | 6,497 | 3,437 | 4,381 | 21,376 |
| 1962 | 1,474 | 6,143 | 2,501 | 5,257 | 3,046 | 18,421 |
| 1963 | 2,191 | 3,829 | 4,012 | 2,109 | 2,711 | 14,852 |
| 1964 | 4,230 | 4,515 | 2,421 | 3,868 | 2,030 | 17,064 |
| 1965 | 1,795 | 5,497 | 2,700 | 3,840 | 2,101 | 15,933 |
| 1966 | 7,901 | 6,959 | 3,821 | 5,361 | 9,368 | 33,410 |
| Total | $46,734 | $46,503 | $50,506 | $32,181 | $29,098 | $205,022 |

## TABLE 47

## ECONOMIC ANALYSIS OF THREE TYPES OF CONDENSERS FOR RENDERING PLANTS[265]

| | Capital Charges (U.S. Dollar Equivalent) | | |
|---|---|---|---|
| Condenser Type | Basic Cost | Installation | Total |
| Direct-spray condenser | | | $2,000 |
| Surface condenser with cooling tower | $3,550 | $1,550 | 5,050 |
| Air-cooled condenser | 4,320 | 1,000 | 5,320 |
| | Operating Charges[a] | | |
| | Water Cost[b] | Electricity Cost[c] | Total Cost |
| Spray condenser | $850 | $ 56 | $906 |
| Surface condenser | 29.75 | 168 | 198 |
| Air-cooled condenser | | 280 | 280 |

[a] Based on a 2,500-hour working year.

[b] Water: 17 cents/1,000 gal.

[c] Electricity: 2 cents/unit.

# APPENDIX C

# OLFACTION THEORIES

## The Dyson-Wright Vibration Theory

In 1937, Dyson[69] proposed three requirements for an odorous substance: volatility, lipid solubility, and intramolecular vibrations which give rise to Raman shifts in the region 3,500 to 1,400 $cm^{-1}$. Dyson[68] had actually proposed the essential factor of vibrations in 1928, the year the Raman effect was discovered; then in 1937 he suggested that the vibrational frequencies of molecules could be assessed from the Raman shifts. Based on limited data, he proposed the region 3,500 to 1,400 $cm^{-1}$ as the region of "osmic frequencies" to which the nose was sensitive. Because the senses of hearing and vision involve sensitivities to vibrations of certain frequencies, a theory of olfaction based on an analogous mechanism is logically appealing. This theory attracted much interest, but it was quickly discarded for the simple reason that there is no correlation between frequencies in the 3,500 to 1,400 $cm^{-1}$ range and odors. Because the Raman and infrared spectra are related, the correlation between odor and frequencies of 3,500 to 1,400 $cm^{-1}$ would have to be correlated with the functional groups now known to give rise to absorptions in this range.

Dyson's theory was ignored for 20 years until it was resurrected by Wright in 1956.[307] Wright believed that the basic idea of vibrational frequencies to which the olfactory receptors are sensitive is correct, but that Dyson's selection of the range of osmic frequencies was wrong. It is known that infrared absorption resulting from the molecular vibrations occurs in the low frequency region (the fingerprint region of infrared spectra), and Wright proposed the region 500 to 50 $cm^{-1}$, in the far infrared, for osmic frequencies. In his theory, the vibrational frequencies determine the quality of an odor, whereas such factors as volatility, adsorbability, and water-lipid solubility determine the intensity of the odor. The olfactory pigment is proposed as having all its molecules in an electronically excited state; the molecules do not return to the ground state unless triggered. The odorous molecule combines with a pigment molecule whose vibrational frequency it matches, thereby changing the frequency of vibration of the pigment molecule and triggering the return of the electronically excited molecule to the ground state. To account for the variety of odors, there must be a number of types of olfactory pigments.

From the generalization that no instances are known in which one of a pair of optical isomers has an odor and the other does not,* Wright[306] infers that the primary process of olfaction must be a physical rather than a chemical interaction. He thinks that the slight differences reported in the odors of some optical isomers may result from different levels of purity. The change in quality of an odor upon dilution is probably due to the odors consisting of several odors having different thresholds, so that at lower concentrations only certain components are detected. Wright[307] acknowledges three exceptions to his theory--ammonia, hydrogen sulfide, and hydrogen cyanide--none of which has low frequency vibrations.

Experimentally, Wright's vibrational theory was at the same state in 1966 as Dyson's theory was in 1937; namely, there were few data to test the theory.[234]

## The Moncrieff-Amoore Stereochemical Theory

In 1944, Moncrieff[184] proposed a new theory: namely, that the only prerequisites for odor were volatility and suitable solubility. According to this theory, differences in intensity of odors were due to variations in volatility, whereas differences in quality were due to different solubilities in the lipoproteins of the various types of receptor cells, with each type sensitive to some fundamental odor. In 1949 he presented a revised theory[185] in which the two prerequisites were volatility and a molecular configuration complementary to the sites of the receptors. The latter is an example of the lock-and-key concept well known in enzyme and drug theory. He suggested that there are probably between 4 and 12 types of receptor sites, each corresponding to a fundamental odor. No further details were specified. It was claimed that this theory incorporated the good features of most of the earlier theories and could explain most of the important characteristics of olfaction, including the different odors of stereoisomers.[234] Moncrieff's[186,189,190] recent work has been concerned with demonstrating that odorous compounds are readily adsorbed on the olfactory epithelium and with emphasizing the theoretical importance of adsorption in concentrating the molecules and thereby enabling detection of such small amounts of substances.

---

*Moncrieff[190] has reported dihydrocamphenol as an exception to this generalization.

Amoore[11,12,14,15] has developed a detailed theory based on Moncrieff's outline. Two refinements were needed:

first, to determine how many types of receptor sites exist; second, to determine the size and shape of each of the receptor sites. The theory successfully accounts for the identical odors of isotopic molecules and the different odors of stereoisomers, the two chief contradictions to Wright's theory. The change in quality of odor upon dilution can be readily explained by preferential adsorption in various sites. An odorous molecule may fit several sites but have a greater affinity for some of them. At high concentrations all sites will be occupied, whereas at low concentrations only the preferred sites will be occupied.